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SCIENCE NEWS BY AGU

A 1928 Dirigible Tragedy

Saving a Pagoda's Dome

How to Measure the World's Sand

SATELLITE RECON

Scientists are using remote sensing from orbit to hunt for underwater volcanoes, predict allergy seasons, and even plan better cities.

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Bringing Satellite Observations Down to Earth

Who would have guessed that an important tool in a mayor's planning kit would one day be a NASA satellite? Environmental hazards are becoming a larger part of every city leader's day, and satellite observations help municipalities not only react to such hazards but also, increasingly, plan for them.

Margaret M. Hurwitz and colleagues write in "Earth Observations Inform Cities' Operations and Planning" (p. 28) about two cities—Chicago and Rio de Janeiro—that are involved in NASA partnerships to incorporate Earth observation data into their planning. Chicago is using satellite data to address air quality and better understand the city's urban heat island. In Rio de Janeiro, city leaders are planning for natural hazards and other effects of climate change. Both cities are proving how global data can be adapted for local use.

In our September issue, we're looking at the ways in which Earth observations can help scientists with their research. With so much data publicly available from national space agencies like NASA and the accessibility and reduced costs of launching CubeSats, it's important to consider the many ways in which having an eye in the sky can supplement in situ monitoring.

A great example of this is pollen tracking. On p. 34, Ghassem R. Asrar and colleagues explain that on the ground in the United States, there are not nearly enough stations per capita for pollen counting—a labor-intensive endeavor. Physicians concerned with the rising number of people affected by asthma and seasonal allergies recently gathered to discuss the problem. They've already implemented a network of cameras on towers throughout the United States, but they're realizing that existing satellite observations of vegetation can offer important supplementary data that show the start, peak, and end of pollen season. This geohealth collaboration between medical professionals, public health experts, and geoscientists using Earth observation data could allow many of us quite literally to breathe easier.

Remote sensing can also be used for novel purposes—like hunting down the origins of pumice rafts. In "Detecting Underwater Eruptions Through Satellite Sleuthing" (p. 22), Philipp A. Brandl writes about how he and his team were able to trace the source of a raft floating in the South Pacific Ocean to "Volcano F." Combining seismic data with satellite data was crucial to their endeavor.

Finally, be sure to read about the efforts by Benjamin Keisling and colleagues on page 17 to diversify their university's seminar series. With all the attention being paid to making the geosciences more inclusive, it might seem overwhelming to try to fix everything at once. Keisling's group shows how to focus on a specific problem and assess its challenges. Tear this article out and hang it by your desk as an example and a reminder that we can all make changes, one step at a time.

Heather Goss

Heather Goss, Editor in Chief

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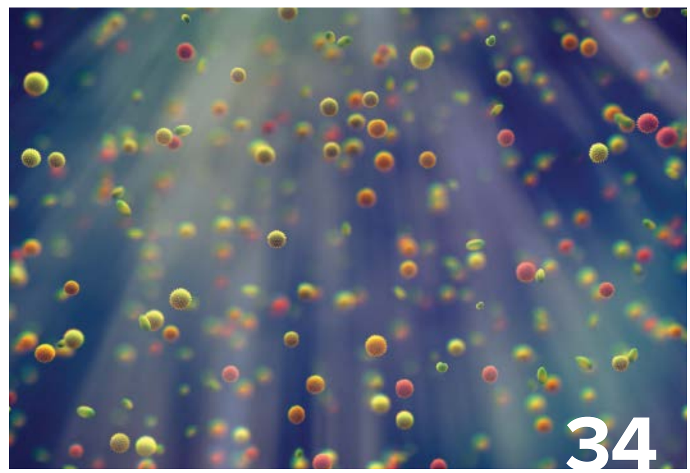
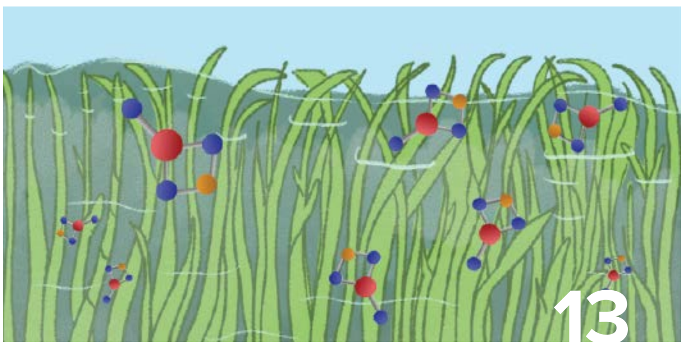


Features

On the Cover

An image from NASA's Terra satellite of the Philippines' Lingayen Gulf showing the aftermath of super typhoon Mangkhut in 2018. Credit: NASA/METI/AIST/Japan Space Systems, and U.S./Japan ASTER Science Team



Columns

From the Editor

News

Opinion

Research Spotlight

Positions Available

Postcards from the Field

AquaSat Gives Water Quality Researchers New Eyes in the Sky

The distinctive green of chlorophyll a, *as seen on this algal bloom in Lake Erie, is one of the patterns used to create the innovative AquaSat data set. Credit: NASA Goddard Space Flight Center*

Nandita Basu studies how human activities can impact water quality, specifically how nutrient runoff can impact large areas. Think of the Mississippi River basin or the Chesapeake Bay watershed. Much of the work Basu, a professor of water sustainability and ecohydrology at the University of Waterloo in Canada, does looks at nitrogen and phosphorus concentrations in streams and rivers and then links them to sources in the landscape, such as agricultural land use.

It's work that necessarily depends on physical sampling of water in the field, but as Basu notes, researchers quickly find fundamental limits in this type of work.

"When you work with these water quality data, one thing that immediately becomes really evident is the *lack* of data. There are millions of streams, and there are only so many that we can go take samples from all the time," she said.

That's why Basu is so excited about AquaSat, a new data set from researchers at Colorado State University, the University of North Carolina, and others that correlates water quality samples from U.S. rivers, streams, and lakes with more than 30 years of remote sensing images taken by Landsat satellites operated by NASA and the U.S. Geological Survey.

"The AquaSat data set is absolutely amazing," she said. "I can imagine using it quite extensively."

Remote Eyes on Water Quality

Matthew Ross, an assistant professor of ecosystem science and sustainability at Colorado State University, is the lead author of a 2019 paper in *Water Resources Research* detailing the AquaSat project (bit.ly/AquaSat). As a postdoctoral researcher in Tamlin Pavelsky's lab at the University of North Carolina at Chapel Hill, however, Ross became interested in using satellites for larger-scale measurements. "I was sort of surprised that more people weren't using remote estimates of water quality," he said.

> **"When you work with these water quality data, one thing that immediately becomes really evident is the lack of data."**

The eight Landsat satellites have provided continuous and global imaging of terrain since 1972. Although those missions have focused on land, Ross and his colleagues realized that there should be "optically relevant" parameters in images of water too, meaning "things that change the color of water." For AquaSat, they were interested in chlorophyll *a,* a measure of algae in water that turns it green; sediment, which can yield a tan color; dissolved carbon, which can darken waters and is a measure of carbon leached from the landscape; and Secchi disk depth, a measure of total water clarity.

Ross and his colleagues then correlated images taken by Landsat 5, 7, and 8 between 1984 and 2019 with on-the-ground samples of the imaged bodies of water that measured the optically relevant parameters. Researchers pulled sample data from the U.S. Water Quality Portal and the Lake Multi-scaled Geospatial and Temporal Database (LAGOS) data set, both of which record water quality measurements in U.S. streams, rivers, and lakes. The resulting 600,000 matchups of remote sensing and sample data allow for more reliable predictions of water quality based on future Landsat imaging alone.

"It gives you a ground truth. It's basically a way to calibrate models that are using Landsat to estimate water quality parameters," Ross said. "We can use these more data-rich, empirically driven ways of prediction that previously weren't available because no data set like this existed before we made it."

Applications and Accessibility

"With this data set we can look at all of these lakes and rivers and look at the water quality trajectories over time," Basu said. For instance, researchers can track the water quality in a particular river over a 30-year period and correlate it with land use and farming practices in the surrounding landscape to estimate their impact. "Maybe," she noted, "the farming practices have not changed that much, but maybe it's climate that's changing the conditions."

Ross hopes to do more than just provide a new and useful data set for other water quality researchers. "Our goal is to make it a lot

easier for anyone to use [the AquaSat data set] to build models that predict water quality," he said.

He has already seen some evidence that this is happening. The AquaSat data set is on Figshare (an open-access repository for figures, data sets, images, and videos), where it has attracted some amateur attention (bit.ly/Figshare-AquaSat).

"I've gotten a bunch of high school and early college computer science folks emailing me about how to train neural nets on our data," Ross said. "Those emails are always exciting because of the idea that there's a bigger community that can engage with the data in an easier way."

Right now, building models and making water quality predictions require some coding skills, but Ross said the ultimate goal is to create a user-friendly interface that could be used by water quality and environmental professionals to make decisions about water resources, such as reservoirs. "Getting these data and ideas into the hands of municipalities is certainly one of my long-term goals," he said.

Beyond creating more user-friendly access to AquaSat going forward, Ross says he hopes to extend the data set with additional satellite imagery, such as the NASA Moderate Resolution Imaging Spectroradiometer (MODIS), satellites, and future missions.

"I'd say the biggest game changer for doing full-stack hydrologic sciences from space is the SWOT mission, which is launching in 2022," he said. The Surface Water and Ocean Topography satellite will provide the water height of large rivers and lakes. These data, according to Ross, could be combined with Landsat color information to allow researchers to do things like estimate the discharge and sediment volume in an ungauged river.

But the future projects Ross is most excited about involve getting enough on-the-ground data to validate satellite imagery in parts of the world that have little water quality data available to begin with. "In places that are changing rapidly, like in Honduras or Brazil, South Africa or other places, going back in time with Landsat satellites there is incredibly valuable," he said. "To me, that's one of the biggest value adds and why it's so important to make this data set global, so we can validate a more global model."

By **Jon Kelvey** (@jonkelvey), Science Writer

Space Weather Lessons from a 1928 Dirigible Tragedy

The airship Italia*, shown above in what is now Stolp, Poland, in 1928, crashed later that year after returning from a journey over the North Pole. Credit: German Federal Archive, CC BY-SA 3.0 DE (bit.ly/ccbysade3-0)*

On 15 April 1928, when the dirigible *Italia* lifted off from Milan, Italy, the crew hoped it would be the second airship ever to reach the North Pole. Over a month later, on 24 May, expedition leader Umberto Nobile sent a triumphant radio message to a ship anchored at the airship's base camp near Ny-Ålesund, in the Norwegian archipelago of Svalbard: The mission was a success. But it would be the last message the base camp would ever receive from the *Italia.*

Ten days later, a young Russian with a homemade radio picked up a desperate SOS signal originating 1,900 kilometers (1,180 miles) away. The *Italia* had crashed on sea ice north of Svalbard on its return journey, killing 17 and leaving nine surviving crew members attempting desperately to contact the base ship to send help. The shipwrecked crew could pick up a news station from Rome, 4,000 kilometers (2,485 miles) away, but no matter what frequency they tried, their cries for help could not reach their camp on the other side of the Svalbard Archipelago. The stranded crew were eventually rescued after weeks on the ice.

"This was completely mysterious to them, I'm sure," said Delores Knipp, former editor in chief of *Space Weather* and a research professor at the University of Colorado Boulder. "They could not understand how they could receive a signal from Rome—very distant—but not be able to contact what appeared to be a very close-by potential rescue ship."

Unbeknownst to the *Italia*'s crew, their plight was caused by an unlucky confluence of space weather disturbances, according to a new retrospective analysis by a team of Italian researchers published in *Space Weather* (bit.ly/Italia-shipwreck). The crew had crash-landed in what is known as a radio skip zone, where radio signals can't be received, during a period of turbulent solar and geomagnetic activity that prevented the signal from getting through.

"This is a history lesson that could replay during other explorations such as lunar or interplanetary travels, so possible communication issues due to disturbed space weather conditions must be taken in due consideration even more nowadays," said Ljiljana Cander, a visiting scientist at the Rutherford Appleton Laboratory in the United Kingdom and a coauthor of the study.

A Different Kind of Storm

High-frequency radio communication takes advantage of a layer of the atmosphere ionized by solar radiation, which extends from 50 to 1,000 kilometers above Earth's surface. Space weather is the term for the phenomena—often solar and electromagnetic disturbances—that affect this layer.

In 1928, radio was still a nascent technology and one that had been used largely at midlatitudes. Few explorers had attempted to reach the North Pole, and fewer still had succeeded. They knew that the poles were capable of brutal terrestrial weather events with howling winds and icy conditions. But they had no real concept of space weather or any idea that it behaved dramatically differently at northern latitudes as well.

Explorers knew that the poles were capable of brutal terrestrial weather events with howling winds and icy conditions. But they had no real concept of space weather.

"Our midlatitude regions are pretty well behaved. We have to have really severe space weather storms to disrupt high-frequency radio communication," Knipp said. But at the transition from midlatitude to polar regions, the ionosphere gets turbulent. It fluctuates more day to day and is more heavily affected by geomagnetic activity. This causes both longer-term radio disruptions and shorter-term blackouts.

Skip zones, or silent zones, are areas where the radio signal cannot reach the ground, meaning that a radio transmission can't be received within the skip area. These silent zones occur near all radio transmitters, but their size is influenced by the electron density of the ionosphere, which fluctuates more at the poles. Polar latitudes also have unique ionospheric disturbances like polar cap absorption resulting from solar eruptions and auroral radio absorption caused by fluxes in energetic electron activity from the magnetosphere.

An Expedition on Thin Ice

As some of the first polar explorers, the crew of the *Italia* became unwitting participants in the earliest known demonstration of what happens when several of these absorption events conspire to disrupt a signal at the same time. When the airship crashed on the ice, the nine survivors immediately attempted to contact the base ship using a portable high-frequency radio. Signals fluctuated between the 9.1- and 9.4-megahertz frequencies, to no avail.

The dirigible had crash-landed in a silent zone for those particular frequencies, which extended across most of the Svalbard Islands and made it impossible for the crew to contact their base. A geomagnetic storm flared up for several days after the crash, potentially further restricting the range of radio frequencies that could get through.

"The combination of the two—a lowering of usable frequencies and an increase of the absorption—might have caused either a narrowing of the usable frequency spectrum or even a blackout that lasted for a few days, preventing the survivors from being heard," said Michael Pezzopane, a researcher at the Istituto Nazionale di Geofisica e Vulcanologia and a coauthor of the study.

To the North Pole and Beyond

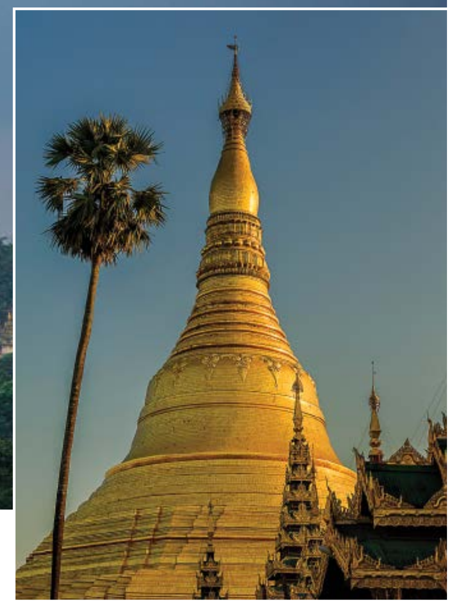
The plight of the *Italia* crew is still relevant today. Space weather as a discipline has been officially recognized only since the 1990s, and our understanding of space weather still lags behind our understanding of traditional weather patterns. Analyzing key space weather events from the past using modern technology and understanding can help us avoid similar pitfalls in the future.

"I do think these historical reconstructions are useful, especially from the point of view of generating awareness for space weather and how it can either adversely or positively affect what we do here on Earth," said Nathaniel Frissell, an assistant professor in the Physics and Engineering Department at the University of Scranton in Pennsylvania who was not involved in the study.

"The people who were involved in this event were very much explorers and frontiers people," Knipp said. "We can draw a parallel with that now for humanity as we try to go back and establish some kind of base on the Moon and as we reach out to cross to a new planet—Mars."

By **Rachel Fritts** (@rachel_fritts), Science Writer

A Golden Opportunity to Save Shwedagon Pagoda's Acclaimed Dome



The gilded dome of Shwedagon Pagoda, above, is created by gluing sheets of gold foil to a copper base. Credit: Getty/Vincent Boisvert

Shwedagon Pagoda is hard to miss.

Sitting atop a hill in Yangon, the largest city in Myanmar, the pagoda's main stupa, or dome, rises over 112 meters into the air and dominates the urban skyline.

It is also encrusted with over 7,000 diamonds, rubies, and sapphires and covered completely in gold—with anywhere from 9 to 60 tons of the precious metal.

But over time, the gold leaf peels and flakes off, so the temple needs to be renovated every 4 or 5 years. In fact, a small gold mill was recently constructed within the Shwedagon compound to help produce and supply the gold needed for restoration.

This restoration process is expensive but necessary: At an estimated 2,600 years of age, Shwedagon Pagoda is one of the world's oldest Buddhist temples and Myanmar's most sacred.

Now materials scientists in Belgium are researching what exactly is causing the gold to peel—and what can be done to make the dome more durable to Myanmar's temperature and humidity.

Last November, Herman Terryn, an engineering professor at the Free University of Brussels, was invited by the Myanmar government to speak at a special workshop investigating better and more durable ways to replace the gold dome. The visit has led to an ongoing collaboration, led by graduate student Lise Vermeersch, with Yangon Technological University, Shewedagon's on-site museum, and Myanmar's Ministry of Religious Affairs and Culture to study why the structure is failing and new methods for future renovations.

"I was very excited that someone is studying this," said Sameh Tawfick, an assistant professor of mechanical engineering researching solid materials at the University of Illinois. "And it's useful beyond this temple. Even in modern architecture, there are so many gilded structures."

Weathering the Material Problems

Shwedagon's dome is made up of thousands of gold plates, made by gluing gold foil to a copper base. The connection between each component of the plate—the gold, glue, and copper—may be weakened by environmental conditions.

The temple is located near a sea in the monsoon region of Asia, so persistent humidity and salty rains can damage components of the dome.

"We know that saline environments can corrode copper," said Vermeersch. And it's possible that it affects the bond between the gold and glue. "That is something that is known, but it really depends on specific conditions, so that is something that should be tested."

But the greatest threat may be temperature variations. "The most challenging part is how all of these conditions will change as a function of temperature cycle, whether between night and day or between seasons," said Tawfick, who was not involved in the research.

"The fact that the temple is in the Sun [means] it will heat up quite a lot," Vermeersch said. "The gold and copper and glue will have different expansion factors, and this will cause a difference in expansion, therefore some thermal stresses."

Climate change thus threatens both the world's future and its history. With more extreme weather and temperature fluctuations expected in the coming decades, the thermal stresses on Shwedagon's golden dome will likely grow.

"When the variations become more extreme, the problem will be even larger," Tawfick said.

Birds can be another source of initial wear and tear, as they can literally peck at the dome surface when hunting for food. "There might be a kind of mechanical impact from a bird pecking which may [cause] some local failure of the gold," Terryn said.

Vermeersch will first test what is in the glue that binds the gold and copper together, using a variety of techniques to analyze and visualize its physical composition at an atomic scale.

The researchers plan to then test lab-made gold plates using the same materials and glue in a climate chamber that exposes the samples to levels of humidity, temperature, salinity, and ultraviolet rays similar to those the Shwedagon Pagoda is subject to. By comparing the artificially aged gold plates with the samples from the actual dome, the researchers hope to understand the mechanisms behind the deterioration.

Unplanned Pause in Research

Unfortunately, the coronavirus pandemic has disrupted the project. The researchers received samples from the dome in mid-February, but the lab was closed by 8 March, Terryn said. Communication with collaborators in Myanmar has been difficult, and a planned trip in the fall may not be able to happen.

Despite these difficulties, the research may provide novel solutions to preserving this temple and other buildings facing similar problems around the world.

"I'm very enthusiastic about this temple" because you're able to visit and see Buddhism practiced, Terryn said.

And by trying to preserve this unique and ancient cultural heritage, the research may uncover new innovations in materials science as a field.

"Although the problem is ancient, I think even the most advanced solutions may not work, and this research may require out-of-the-box ideas or solutions tailored for a specific problem, not an existing solution," said Tawfick.

By **Richard J. Sima** (@richardsima), Science Writer

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Heavy Rains, Human Activity, and Rising Waters at Lake Victoria

In summer 2020, shoreline homes were flooded by the rising water levels of Lake Victoria. Credit: Hope Mafaranga

Over the past year, Lake Victoria's waters have been advancing. The great African lake has risen a meter since October 2019. The lake's rise is due to rainfall and increased runoff caused by human activities around Lake Victoria and the rivers that feed it.

Lake Victoria is a huge transboundary body shared by Kenya, Tanzania, and Uganda. Twenty-three rivers feed the lake. Some of these rivers originate hundreds of kilometers away; when it rains in Burundi, the water finds its way to Lake Victoria.

"The rivers discharging water into Lake Victoria from upstream countries have more than doubled their inflows," in part because of heavy rains, said Sam Cheptoris, Uganda's minister of water and environment. Lake Victoria has only one outlet, the White Nile. "This water flows through South Sudan and Sudan and ends up in the Mediterranean Sea through Egypt," Cheptoris said. Water releases at Jinja (the headwaters of the Nile in Uganda) had increased to 2,200 cubic meters per second through July, up from 1,000 cubic meters per second last October.

Human Impacts on Water

"Uganda faced the same [amount of] rainfall between 1961–1964 and 1996–1998, which resulted in a rise in the levels of rivers and lakes" in the region, Cheptoris said, but the current situation has been worsened by environmental degradation and urbanization associated with drought in 2016–2017. Many Ugandans, 80% of whom rely on agriculture for their livelihoods, were forced to relocate to the shores of Lake Victoria or find work in industries such as forestry and fishing.

These human activities have accelerated the quick rise of Victoria's waters, said Alfred Okot Okidi, the permanent secretary of the Ugandan Ministry of Water and Environment. "Loss of forest cover, encroachment on wetlands, lakeshores, and riverbanks, including poor land use practices, have resulted in soil erosion, leading to siltation of our water bodies," he said.

Okidi added that urbanization has increased the amount of impermeable surfaces such as roads, roofs, and pavements, reducing water penetration into the soil and increasing the amount of runoff flowing to storm drains and other discharges. Urban-

ization has also reduced the evapotranspiration capacity of forests and wetlands surrounding Lake Victoria.

Water Impacts on Humans

As the lake's level has risen, essential facilities such as drinking water and sanitation systems, health facilities, roads, and even hydropower stations have been affected. Water-related diseases such as cholera, dysentery, malaria, and schistosomiasis could increase, said Charles Olaro, director of clinical services for the Ugandan Ministry of Health. "The rise of Lake Victoria is worrying. We are struggling to contain the spread of coronavirus. It will drain the already stressed health system that is operating on minimal funds."

The increased water level dislodged papyrus mats from shorelines, resulting in huge floating plant islands, which threaten hydropower infrastructure. In mid-April, one such papyrus mass docked at Nalubaale Hydro Power Station, choking turbines and resulting in a temporary Uganda-wide power blackout.

"These floating islands, too, have the capacity to block waterways and other economic activities within the water bodies," said Okidi. Farther downstream, ferries along the Nile River have been suspended, as jetties and landing sites have been submerged.

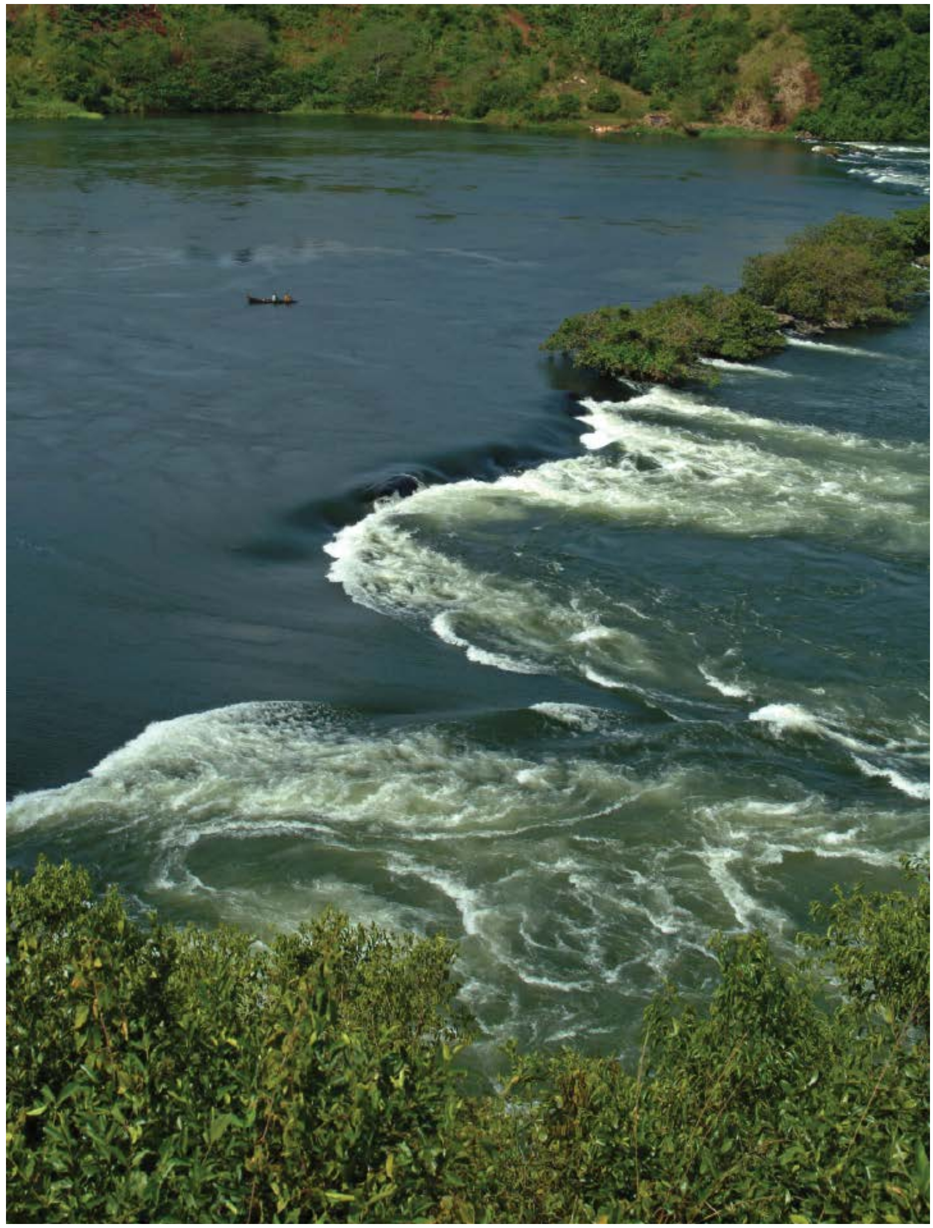
Okidi said that since the water started rising, over 200,000 people have been displaced and left homeless. Property worth millions of Ugandan shillings has been destroyed, from single family homes to large shoreline resorts.

Next Steps

In early July, Uganda's central government threatened to fire officials who had not taken action against people building in sensitive areas around the lake. The water ministry evicted people who had settled within the protected zones of wetlands, lakes, rivers, and forest reserves.

According to the Ugandan Ministry of Water and Environment policy, people must settle 100 meters away from riverbanks, 30 meters away from wetlands, and 200 meters from lakeshores. Cultivation on steep slopes also must come to a halt to reduce erosion and high runoff from hilly areas.

Dora Byamukama, one of Uganda's members of parliament in the East African Legislative Assembly (EALA), said that countries sharing Lake Victoria have similar regulations, instituted by each country's respective National Environment Management Authority in consultation with EALA.



The outflow of Lake Victoria at Jinja, Uganda (above in 2006), is the headwaters of the White Nile. Credit: Aldo Pavan/The Image Bank/Getty Images

Human impacts, nevertheless, are expected to continue from activities like sand mining, forestry, and agriculture, which all use water from or encroach on the lake. Threats from climate change, such as more frequent instances of the El Niño–Southern Oscillation, also continue to disturb the shores of Lake Victoria, said Revocatus Twinomuhangi of the Department of Geography, Geo-Informatics and Climatic Sciences at Makerere University in Kampala, Uganda.

"Climate change is becoming [more of] a reality than ever before, and if we do not stop human activities along the lakeshores, water catchment areas, and reserve forests, we are heading to some disasters that [African countries] have no resources to handle," Twinomuhangi warned.

By **Hope Mafaranga** (@mafaranga), Science Writer

To Protect the World's Sand, We Need to Know How to Measure It

Mining operations like this one in the Czech Republic extract up to 50 billion metric tons of sand every year. Credit: rusm/E+/Getty Images

Sand is such a sought-after resource that by volume, the amount we use is second only to water. Sand is crucial for manufacturing concrete, glass, and asphalt and even everyday items like paper and toothpaste. And an increasing portion of the 40–50 billion metric tons of sand mined each year comes from the world's beaches, which are threatened by rising sea levels due to climate change.

The smooth, round grains of quartz in desert sand are useless for many of our sand needs—we require rougher stuff, like the crushed corals and shells that make up the carbonate sands of tropical beaches. This means that managing and accounting for this valuable sand will become more critical in the coming years, but according to a recent study published in *Scientific Reports,* we have been measuring carbonate sand all wrong (bit.ly/carbonate-sand). The study proposes a new, updated method that takes carbonate sand's sought-after variety in shape and size into account.

"Our new method will help to estimate more accurately the sediment transport of carbonate sands in tropical environments," said Ana Vila-Concejo, an associate professor at the University of Sydney School of Geosciences and a coauthor of the paper. "This can directly translate into more accurate coastal management of eroding sandy coasts."

A Fortuitous Collaboration

From her research on sand hydrodynamics, Vila-Concejo long suspected that carbonate sand transport models were inaccurate, but she could never convince her students to tackle the problem of making better-suited models. Then, Amin Riazi, at the time an early-career research assistant at Eastern Mediterranean University, sent her an email out of the blue. "He had exactly the right skills and was interested in pursuing this research," Vila-Concejo said.

"As I was discussing the topic with Prof. Vila-Concejo, I realized that surprisingly, and contrary to plenty of studies on other sand types, there is a lack of research related to the settling velocity and the drag coefficient of carbonate sands," said Riazi, now an assistant professor at Cyprus International University. He traveled to the University of Sydney for a short research stay, and he and Vila-Concejo got to work on the carbonate sand problem.

Carbonate Sand Is a Drag

Most equations for sediment transport are based on experimental results from smooth silicate sands, making them a poor fit for beaches, where most of the sand is made up of small bits of shell and coral. Because carbonate sands have more irregular shapes, they have larger drag coefficients than desert sand and move more erratically through the water. This drag, in turn, makes individual grains' settling velocity much more variable, effectively spreading out the sand grains over a wider distance when they are suspended in water.

"If the settling velocity is not correctly accounted for, sediment transport models will give wrong predictions of beach erosion or accretion," said Kwok Cheung, a professor in the Department of Ocean and Resources Engineering at the University of Hawai'i at Mānoa. Cheung provided the raw data used to help calculate the new drag coefficient but was not involved in the study itself. "This will have severe consequences for beach management or nourishment projects."

Most equations for sediment transport are based on experimental results from smooth silicate sands, making them a poor fit for beaches, where most of the sand is made up of small bits of shell and coral.

Riazi and Vila-Concejo and their coauthors found that existing models typically underestimate the surface area of carbonate sands by over 30%, overestimate the transport of these rougher grains over the seafloor, and underestimate transport of sands when they are suspended. The researchers hope that their model will be implemented by coastal engineers and others who need to evaluate the way sandy beaches respond to ocean currents, waves, and the long-term impacts of sea level rise.

"The new model provides a more accurate description of the settling velocity, which is a primary input parameter for sediment transport calculations," said Cheung. "The better the input, the better the output."

Managing a Crucial Resource

Accurate accounting of the sand that makes up tropical beaches will become more important in the coming years. As sea levels rise, beach managers and coastal engineers will need to decide how best to preserve beaches as both a crucial coastal habitat and a natural coastal barrier. "When preparing for the impacts of climate change, the accuracy of our equations will mean that we don't need to overengineer and use more sand than strictly necessary," said Vila-Concejo. "This can directly translate [into] more accurate coastal management of eroding sandy coasts."

Better accounting is also important in light of sand mining's increasing intensity and the threat it poses to coastal and marine ecosystems. A construction boom in Asia and Africa has driven up the demand for sand in the past 2 decades, and the resource is expected to become much more sought after—and scarce—in the coming years.

"We need to better monitor changes in sediment transport, as we're seeing increasing human impact on natural systems," said Mette Bendixen, a research fellow at the Institute of Arctic and Alpine Research at the University of Colorado Boulder who commented on the phenomenon in *Nature* last year (bit.ly/sand-scarcity). "Despite the central importance of sand, we don't possess any clear global overview, or statistics, of the sand resources available or those being mined. If we don't have this overview of what we actually have available as a resource, we're putting sustainability of the environment, and people's livelihoods, at risk."

By **Rachel Fritts** (@rachel_fritts), Science Writer

The Rise of Zombie Fires

An image of northern Siberia taken on 5 May 2020 by NASA's Terra satellite with hot spots marked in red (enhanced here for visibility). Credit: NASA Worldview; bit.ly/NASA-zombie-fires

In early May, just as the spring thaw was beginning in the northern reaches of Siberia, Mark Parrington spotted something strange on images captured by instruments aboard NASA's Terra satellite. Red dots, indicating some kind of thermal anomaly, stood out on a vast white expanse.

Fueled by methane deposits and insulated by a layer of snow, zombie fires can burn all the way through the cold and wet Arctic winters.

Parrington, a senior scientist at the Copernicus Atmosphere Monitoring Service, posted one of the images (above) to his Twitter account @m_parrington: "Hotspots starting to appear in NASA MODIS & VIIRS [observations] as ice thaws in northern parts of Siberia. Hard to tell if these are fires yet...but it is probably just a matter of time."

Thomas Smith, an assistant professor of environmental geography at the London School of Economics, quickly noticed that the hot spots were located in areas that had burned in last year's epic Arctic fires.

"Whatever they are (land clearance? natural?) they were occurring at the same time last year," Smith wrote, posting a picture of the same location from 2019.

"Zombie fires?" Parrington replied.

Burning Between Fire Seasons

"Zombie fires" is a new and catchier name for an old and relatively rare phenomenon. Known among Arctic fire managers as holdover or overwintering fires, zombie fires transcend the typical fire season.

After flaming wildfires are extinguished on the surface, they can continue to smolder belowground, burning through peat and other organic matter. Fueled by methane deposits and insulated by a layer of snow, zombie fires can burn all the way through the cold and wet Arctic winter. In the spring, as temperatures begin to climb and soil dries out, the fires can reignite aboveground.

Although records of zombie fires go back decades, the phenomenon wasn't extensively studied until recently.

Researchers noticed that these early spring fires seemed to pop up more often after large fire seasons and often near the burn scars left by the previous fire. This couldn't be a coincidence, thought Sander Veraverbeke, an assistant professor at Vrije Universiteit Amsterdam. Veraverbeke and Rebecca Scholten, a Ph.D. student at the university, have carried out some of the first scientific studies on zombie fires.

The pair analyzed records from Alaska going back to 2005, showing empirically that zombie fires were more likely after large fire seasons (bit.ly/zombie-fires).

Fire managers in Alaska had noticed the trend. "We noticed clusters of these overwintered fires the spring after some of our big fire seasons in Alaska: 2004, 2005, and

> **"These fires can pop up early, while we're still trying to complete fire readiness and training activities, and before lightning season when we normally expect to be actively managing fires."**

2015," said Randi Jandt, a fire ecologist with the Alaska Fire Science Consortium.

But Veraverbeke and Scholten's study was the first to attempt to detect holdover fires using satellites, according to Jandt.

Aerial photos of the Yukon Flats region in 2005, a year after the Lower Mouth Fire burned through the region, show trees "felled like toothpicks," said Jandt, "due to their roots and soil underneath burning out." That's where smoke first emerged in the spring of 2005.

A Record-Breaking Season

Last year's Arctic fire season was one of the biggest on record. In June and July 2019, more than 100 blazes burned in the Arctic circle. Millions of hectares of boreal forests across Siberia, Alaska, Greenland, and Canada went up in smoke. Clouds of soot the size of the European Union stretched across the sky.

Jandt and her colleagues at the consortium have already identified a few overwintered fires that are active now.

Without on-the-ground confirmation, it's hard to say for sure whether the fires Parrington identified in the Siberian Arctic were actually started by the remnants of last year's blazes. The satellite instruments can detect the fires only once they've reignited on the surface. But Parrington and Smith suspected they may have been burning there all winter long for a few reasons: Arctic fires are typically started by people or by lightning strikes, but these fires emerged in remote areas far away from human settlements, near the areas that burned last year, and before lightning strikes typically pick up in June.

Like all wildfires, zombie fires are sources of carbon emissions. In 2019, Veraverbeke and his team traveled to Siberia and camped out in the burn scars of past wildfires to study carbon combustion. They took soil core samples from burned and control plots to figure out just how much carbon Arctic fires are releasing.

Most people think that most of the carbon released during wildfires comes from burning trees, but that's a misconception, according to Veraverbeke. "Seventy to ninety percent comes from the organic soil," he said. "Trees contribute just a small fraction."

Veraverbeke thinks that the smoldering phase of these fires accounts for only a small portion of wildfire emissions. Though overwintering fires can burn through organic matter and methane stored in the soil, they also tend to stay put. The team's previous research shows that on average, zombie fires account for less than 1% of Alaska's burned land area each year.

They can still be a headache for fire managers. "These fires can pop up early, while we're still trying to complete fire readiness and training activities, and before lightning season (June–July) when we normally expect to be actively managing fires," said Jandt. The upside is that the tundra is usually still cool and wet in the spring, and the fires may be easier to control.

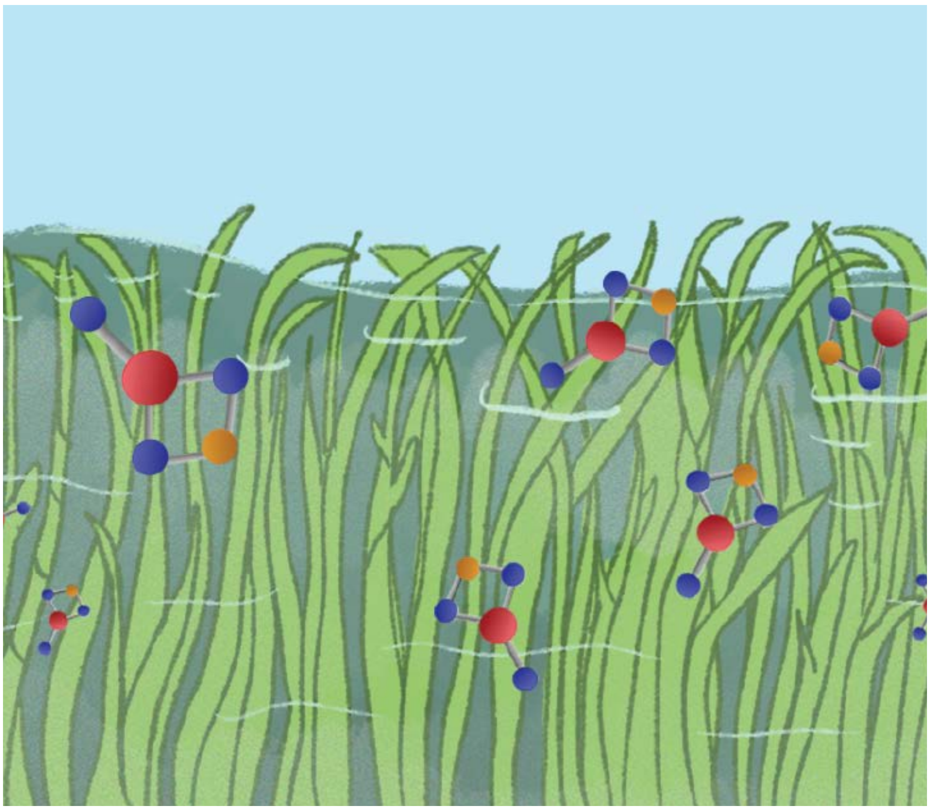
But the Arctic is changing rapidly, and patterns of the past may not hold in the future.

"We know that these large fire years in the boreal forests are already happening more often," Veraverbeke said. Temperatures in the Arctic are rising faster than almost anywhere else on Earth, thawing the permafrost, drying soils, and providing new fuel for blazes. Global warming is also leading to more thunderstorms and thus more lightning strikes—a common ignition source for fires in remote regions.

Veraverbeke and Scholten are currently working on a study to find out how climate change might affect Arctic blazes and zombie fires.

By **Kate Wheeling** (@katewheeling), Science Writer

Aquatic Plants May Help Chesapeake Bay Resist Ocean Acidification



Calcium carbonate in its molecular form is illustrated here as red dots (carbon) linked to blue (oxygen) and orange (calcium), and populating aquatic vegetation beds. Credit: JoAnna Wendel

A Landsat 8 satellite image of the Chesapeake Bay, the United States' largest estuary. Credit: USGS

The Chesapeake Bay stretches nearly 325 kilometers north to south and is 8 kilometers wide in some places. The riparian habitat is home to mammals like bears and river otters, hundreds of species of birds and fish, bottlenose dolphins, and even manatees. The seafood industry in Maryland and Virginia generates more than $3 billion per year and supports more than 30,000 jobs.

In the late 1960s, the bay was plagued by pollution and the loss of submerged aquatic vegetation (SAV). Although conservation efforts have restored SAV beds and improved the overall health of the bay, it's still experiencing local effects of climate change: rising temperatures, oxygen-free dead zones, and acidification. Although the bay's surface pH levels reach around 8.2, its subsurface pH can be as low as 7.4.

Now researchers think that restored SAV beds upstream of the bay could be a key player in the fight against acidification.

Researchers think that restored submerged aquatic vegetation beds could be a key player in the fight against acidification in the Chesapeake.

"This is a very interesting thing," said Wei-Jun Cai, a marine chemist at the University of Delaware and a coauthor of a new study in *Nature Geoscience* (bit.ly/Chesapeake-acidification), in a statement. "People talk about ocean acidification and very rarely talk about what resists it, what can buffer the system against ocean acidification. So that's what we want to find."

Carbon Dioxide Double Whammy

Two sources of carbon dioxide (CO_2) acidify the Chesapeake Bay, Cai told *Eos.* One source is the atmosphere, which is full of anthropogenic CO_2 emissions. The ocean has absorbed roughly a third of that CO_2. Subsequent chemical reactions acidify the ocean water, hampering marine animals' ability to build their skeletons and shells.

The second source of carbon dioxide comes from below the bay's surface, as a secondary effect of eutrophication, Cai said. Eutrophication occurs when nutrient-rich waters encourage algal blooms and those algae die and decompose. The decomposition of the algae leaches oxygen out of the water, leading to dead zones, where animals can't survive.

Eutrophication also releases carbon dioxide.

"Whether the carbon dioxide comes from organic matter decomposition or from an anthropogenic source, it has the same effect," which is acidification, Cai said.

Plants as Buffers

While studying the Chesapeake Bay's pH levels, Cai noticed heightened levels of calcium carbonate dissolved in the subsurface of the bay. At that time, he had no idea where the calcium carbonate came from. One thing was

certain: The carbonate was most likely acting as a buffer to keep the bay's pH from dipping too low.

"If not [for] the carbonate dissolution, the pH could go down to 6.8. Really, really low," Cai said.

After seeing a conference talk about submerged aquatic vegetation, Cai wondered whether something upriver was releasing the calcium carbonate.

He and his team set out to the Susquehanna Flats, a shallow region upstream of the bay that's home to an abundance of submerged vegetation. In testing samples from the dense vegetation beds, the researchers found that photosynthetic processes raised the water's pH and oxygen levels, thus allowing more carbonate to form. They also took plant samples and analyzed leaf surfaces in the lab, on which they found nanometer-sized calcium carbonate crystals under an electron scanning microscope.

"Whether the carbon dioxide comes from organic matter decomposition or from an anthropogenic source, it has the same effect."

Models suggest that the carbonate is produced in the shallower water of the flats and then is washed downstream into the bay, researchers said.

The paper offers "a previously overlooked mechanism in which restoring the SAV beds will likely enhance the buffering capacity of the mid-bay, potentially providing further resiliency in the face of global ocean acidification," said Iria Gimenéz, a researcher at the Hakai Institute in British Columbia, Canada, who has worked with the authors before but wasn't involved in this research.

Cai said that in the future, he wants to better understand the mechanism by which the calcium carbonate reaches the mid-bay region, how long that process might take, and under what conditions this flushing happens.

By **JoAnna Wendel** (@JoAnnaScience), Science Writer

Worsening Water Crisis in the Eastern Caribbean

Many plants in the woodlands of Saint Lucia, above, are not drought tolerant. Credit: georama, CC-BY-3.0 (bit.ly/ccby3-0)

For years, people living in the eastern Caribbean have not had reliable supplies of fresh water: Their homes might go for months without running showers or flushing toilets, let alone potable fresh water on tap.

The region suffers from a severe and worsening water crisis, and this year is breaking records. In May, the government of Saint Lucia declared a water emergency for the island's approximately 180,000 residents. In a Facebook post in early June, Prime Minister Allen Chastanet raised the alarm that the country is "currently experiencing drought conditions said to be the worst in more than 50 years." The island's sole reservoir is at "alarmingly low water levels," Chastanet said, owing to lower than average rainfall made worse by heavy siltation that has reduced the reservoir's capacity by "a whopping 30%."

Although they contribute far less than 1% of the world's greenhouse gas emissions, small island nations like the ones that make up the Organisation of Eastern Caribbean States are among the first to experience the most destructive impacts of climate change: sea level rise, increased storm activity, and

Although they contribute far less than 1% of the world's greenhouse gas emissions, eastern Caribbean islands are among the first to experience the most destructive impacts of climate change.

coastal erosion. One of the inevitable casualties is water supply.

"We are already seeing it. It's like we do not actually have a rainy season in the Caribbean," said Judith Gobin, a marine biologist at the University of the West Indies in Trinidad and Tobago. Climate change has shifted the hydrological cycle in the region, with more intense rainfall and longer dry spells.

Venantius Descartes, senior meteorologist at Saint Lucia Meteorological Services, said that paradoxically, increases in storms and hurricanes as a result of climate change have exacerbated the island's water shortage. As bigger storms bring more water, they destroy infrastructure and lead to contamination, affecting the distribution and quality of the water supply in the region.

The hurricane season this year has already seen two named storms in June, the first month of the Caribbean hurricane season. That's "too soon," according to Dale Destin, a climatologist and director of the Antigua and Barbuda Meteorological Service. The phenomenon has happened only four times since 1886.

Missing Water

Tamisha Daniel, a resident of Bois Patat, Saint Lucia, fears that the current water shortage may become worse. At times when there is "not a drop of water in the house," taking care of her newborn son can feel daunting, said the mother of two. "When to bathe him and to wash his clothes, it's a bit of a challenge because we do not have the water, and to make it worse, it's not raining. So you can't collect water…and it's so hot!" Daniel considers herself lucky, as a neighboring community, Odlum City, has not seen pipe-borne water for over 2 months.

Cleon Athill is vice president of The Movement, an environmental organization that works toward good governance on the island of Antigua, which has a population of over 80,000.

"We see our dams and wells drying up, and our drought periods are getting longer and drier," Athill said. "Farmers suffer the most—they depend on piped water—but this is inadequate and inconsistent. Many residents must haul or buy water, which can be a burden for deprived communities."

The water company that supplies Saint Lucia, for example, relies on the reservoir and river flows, but those flows have been unreliable. Storms might muddy the waters enough that even after treatment the taps deliver sediment-laden water. The company rations water at times, leading residents to seek out friends and acquaintances in other neighborhoods with running taps or to collect untreated water from rivers and waterfalls.

Small island nations throughout the eastern Caribbean are experiencing a similar plight. Tourism dependent, most of the large hotels and resorts that cater to foreign visitors are owned by foreign companies that treat wastewater on site for reuse as nonpotable water and can maintain water tanks filled with tap water. Meanwhile, most local communities do not have the space or funding for large water storage tanks, which can hold enough for months.

Previous drought has led to such measures as charging farmers for extracting water from certain rivers in Trinidad and Tobago and asking residents in Barbados to adopt voluntary conservation methods. Rain-fed agriculture in these island nations means that drought can lead to food insecurity, the Food and Agriculture Organization of the United Nations warned in a 2016 report.

Too Little, Too Late?

Signatories of the Paris Agreement, which came into force in 2016 and builds on years of negotiations under the United Nations Framework Convention on Climate Change, agreed to keep the increase in global average temperature to below 2°C, instead of a far more ambitious target of 1.5°C, as requested by small island developing states (SIDS). A long-term global temperature increase above 1.5°C would be disastrous to SIDS and the eastern Caribbean, contributing to sea level rise, coastal erosion, and loss of habitats.

At the heart of the Paris Agreement is the Green Climate Fund, intended to help the eastern Caribbean region and other SIDS by providing billions of dollars for climate adaptation projects. The initial resource mobilization of $10.3 billion fell to $9.8 billion after the United States withdrew $2 billion of the $3 billion that was initially pledged.

"We see our dams and wells drying up, and our drought periods are getting longer and drier.

Islands in the eastern Caribbean have received funding from other sources, said Gobin, who participated in past projects focused on coastal livelihood strategies. However, she contends that the money is not properly spent, with funding going toward administration and foreign consultants instead of to the technical aspects of local projects.

The Paris Agreement is "too little, too late," said Destin.

"What comes out of this is a lovely report that describes situations. But it lacks that practical aspect for a clean supply of water," Gobin said. She called for a reexamination of this approach.

Cardinal Warde, a professor of electrical engineering at the Massachusetts Institute of Technology and a scientific adviser to the government of Barbados, agreed. "I believe that people in poor communities have reason to believe not much is going to happen," he said.

"Even if there is funding from the Green Climate Fund to deal with adaptation and mitigation," said Eden Charles, a former United Nations ambassador who was the lead negotiator for Trinidad and Tobago for the Paris Agreement, "that doesn't trickle down sufficiently to deal with the plight of the rural poor—the farmers, artisans, and workers—and doesn't deal with whether the fisherman is being impacted and whether there is a greater impact of coastal erosion."

Charles also noted that the Paris Agreement is based on voluntary commitments: "If there is a breach, there is no recourse; if it were legally binding, there would be," he said. One of the largest signatories of the agreement, the United States, has decided to withdraw, a decision that will become effective this November.

The Paris Agreement is "too little, too late," said Destin. "The forecast is for us to get drier in the future [in the eastern Caribbean]. We have missed or [are] about to miss the point of return. We are pretty much at the point where we cannot do enough to prevent hazardous climate change."

By **Sarah Peter** (@SarahPeter3), Science Writer

Ghostly Particles from the Sun Confirm Nuclear Fusion

Deep within the Sun, high temperatures and pressures drive the fusion of hydrogen into helium. Absent these nuclear reactions, Earth would be a cold and dark world devoid of life. Now, using an exquisitely sensitive detector located deep underground, researchers have made the first direct observation of a rare breed of ghostly particles known as solar neutrinos. This discovery confirms a long-hypothesized mechanism for how the Sun—and other stars—fuses hydrogen into helium.

Two Pathways to Neutrinos

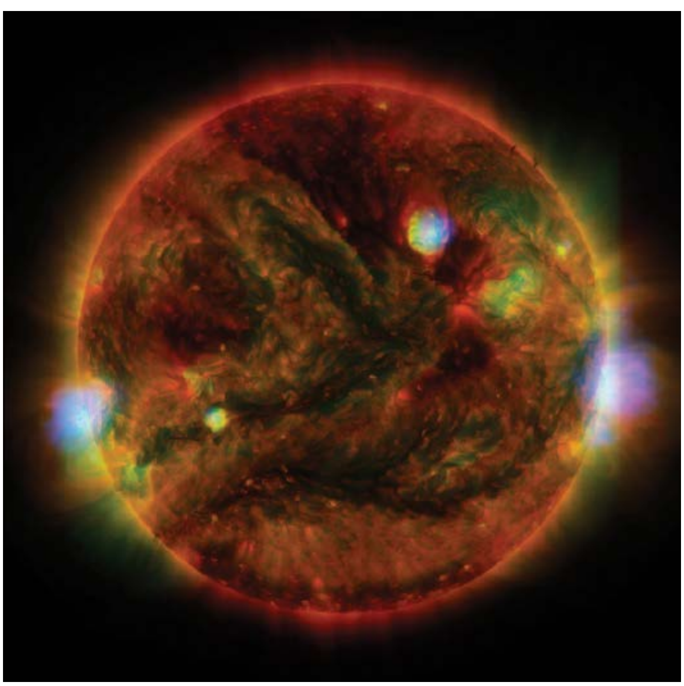
More than 8 decades ago, physicists Hans Bethe and Carl Friedrich von Weizsäcker independently proposed that hydrogen fusion in the Sun might be catalyzed by carbon, nitrogen, and oxygen nuclei. Researchers now understand that this so-called CNO cycle accounts for only a small fraction of the energy produced by the Sun—roughly 1%—but it's a dominant mechanism in more massive stars. Most of the Sun's energy derives from a fusion process known as the p-p chain.

Both the p-p chain and the CNO cycle produce neutrinos. These electrically neutral, nearly massless particles pervade space, yet they're maddeningly tough to pin down because they interact so weakly with matter. "Neutrinos are very difficult to detect," said Sarbani Basu, a solar and stellar astrophysicist at Yale University in New Haven, Conn., not involved in the research. "They pass right through you." (Hold up a hand. Tens of billions of neutrinos just zipped through.)

Neutrinos are a hallmark of the Sun's nuclear reactions, and they're a fundamental way of studying processes that occur deep within our nearest star. But it wasn't until 2014 that researchers reported detecting neutrinos from the primary reaction of the p-p chain. Now that same research group has pinpointed neutrinos from the CNO cycle.

A Detector Deep Underground

The team used the Borexino particle detector located roughly 1,400 meters underground near Rome, Italy. (The detector's subterranean environment shields it mightily—but not completely—from a barrage of cosmic particles.) The heart of Borexino is a spherical tank roughly 4 meters in diameter filled with about 280 metric tons of a liquid hydrocarbon. This "scintillator" liquid emits light whenever a charged particle moves through it. If a neutrino happens to collide with an electron in the tank, the resulting burst of light is captured by photomultiplier tubes within the detector. Neutrinos from the CNO cycle can be distinguished on the basis of the kick they impart to electrons.



Flaring, active regions of the Sun are highlighted in this image combining observations from several telescopes. High-energy X-rays from NASA's Nuclear Spectroscopic Telescope Array are shown in blue, low-energy X-rays from Japan's Hinode spacecraft are green, and extreme ultraviolet light from NASA's Solar Dynamics Observatory is yellow and red. Credit: NASA/JPL-Caltech/GSFC/JAXA

A long-standing challenge to detecting CNO cycle neutrinos has been background contamination. For example, the radioactive decay of bismuth-210, found in the nylon lining Borexino's innermost tank, releases charged particles that can trigger bursts of light, said Gioacchino Ranucci, an astroparticle physicist at the National Institute for Nuclear Physics in Milan, Italy, and a spokesman for the Borexino Collaboration. "Even if it's a small amount, it can mask the signal of the neutrinos."

Insulation to the Rescue

To combat this contamination, the scientists carefully controlled Borexino's thermal environment. They clad the detector in a thick layer of insulation and installed a heater nearby. Those efforts minimized convective currents within the detector's liquid, important for preventing the dispersal of bismuth-210 and its daughter products. The research team also limited its analyses to signals originating from deep within Borexino's innermost tank, far from the detector's nylon lining.

This discovery is "another milestone in solar neutrino physics."

This summer, at the XXIX International Conference on Neutrino Physics and Astrophysics, the Borexino Collaboration reported a confident detection of CNO cycle neutrinos based on 3.5 years of data. Borexino spotted about seven of these elusive particles each day, the team estimated.

This discovery is "another milestone in solar neutrino physics," the team of nearly 100 reported in an accompanying paper (bit.ly/CNO-neutrinos).

These results are exciting, said Basu, but the error bars on the detection are still large. Those will get smaller as more data are collected, so it's important to keep the experiment going, she said. "Keep observing, keep observing."

By **Katherine Kornei** (@KatherineKornei), Science Writer

What's in a Seminar?

In a hallway in the Department of Geosciences at the University of Massachusetts (UMass) Amherst hang posters featuring all the scientists who have participated as invited speakers in the department's weekly seminar series over the past few years. These individuals represent an impressive range of geoscience disciplines, and the posters serve to announce that this department values a variety of research specialties. Yet for underrepresented students who have not always felt seen, welcomed, or a sense of belonging in the department or in the field at large, these posters are also a reminder that most of the scientists our seminar series celebrates are senior, white, and male.

When we volunteered to coordinate the Geosciences Lecture Series for the 2017–2018 academic year, we knew we wanted to do something different. We set clear, concrete goals that we considered achievable within 1 year: At least 50% of the roughly 20 speakers would be women (up from an average of 40% over the previous 4 years), and more than one speaker would be a person of color. We solicited nominations from the entire geoscience faculty via email, but of the 40 nominations we received, only eight were women, and few were nonwhite. We knew it would be difficult to meet our goals from that pool, so we followed up with a specific request for more nominations of white women and people of color, which yielded three additional names. Given that we needed to balance representation of different research disciplines and respect scheduling constraints of invited speakers and faculty hosts, this didn't give us much flexibility to meet our goals.

We brainstormed solutions to diversify the nomination pool. First, we encouraged faculty to nominate a former student or current postdoc of the senior scientist they had nominated. But faculty often preferred their original nominee for a variety of reasons, including that the person was a collaborator or they "didn't know" the senior scientist's students or postdocs. Second, we tried providing our own speaker suggestions and asking faculty to nominate them. However, we were then asked to vouch for these individuals' speaking abilities, or we were told that faculty were uncomfortable inviting someone they didn't know or that there wasn't enough funding to bring speakers from far afield.

With these constraints, we did our best to put together a series for the year that met our goals. In the process, we learned that the challenges we faced in diversifying the seminar series were not unique to our own department, nor are they unique to the geosciences. This made us wonder: What would our ideal seminar series look like?

Nyeema Harris of the University of Michigan gives a BRiDGE2Impacts presentation entitled "The Fierce Urgency of Now to Redefine Impact in Academia" at the University of Massachusetts Amherst in October 2018. Credit: Benjamin Keisling

Building a BRiDGE

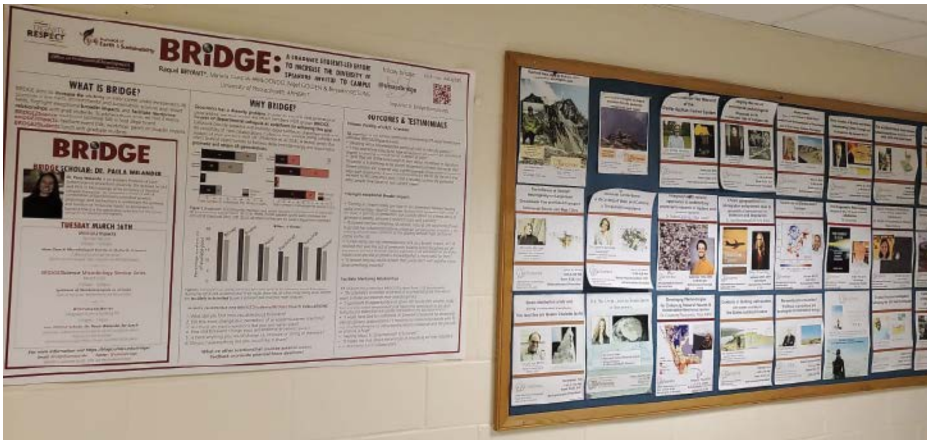
While coordinating the Geosciences Lecture Series, we learned why seminars matter to the members of our community. For our faculty, seminars provide an opportunity to bring established colleagues and collaborators to campus. For invited speakers, visits spark new ideas for projects and collaborations while also filling out the "invited talks" section of their curricula vitae. Seminars expose postdocs and students, some of whom have had few opportunities to attend conferences, to research topics and methods not represented in their departments and help them identify next steps for their own research or careers.

Through our efforts to organize the series, we identified other potential seminar benefits that we wanted to cultivate. For example, we had valuable conversations with early-career faculty visitors about navigating the academic job market, and we wanted more students to have access to those kinds of discussions. We also considered how creating space to highlight the broader impacts of the speakers' research and how it intersects or engages with communities that they serve could increase audience engagement.

We decided our ideal seminar series would involve speakers from underrepresented communities and would provide a platform for these scholars to share experiences and perspectives that inform their research, including about the communities their work serves or the professional and personal obstacles they overcame. It would also provide opportunities for underrepresented students to see early-career scholars who may share their identities or experiences in science, technology, engineering, and mathematics (STEM) and who could provide career advice that is tailored toward students from diverse backgrounds. Above all, we realized that every time we invited a seminar speaker into our community—through invited seminar series that are held in departments across the university—we had the opportunity to meet these needs.

Beginning in 2018, we built a coalition with graduate students in other departments who shared our vision. Through this coalition, we conceived BRiDGE, a first of its kind, graduate student–led, multifaceted seminar series. After successfully applying for a seed grant through a campus-wide diversity initiative, the School of Earth and Sustainability and the College of Natural Sciences at UMass Amherst recognized the ongoing and potential future impacts of our initiative and provided additional support.

BRiDGE encompasses three types of speaker presentations—BRiDGE2Science, BRiDGE2Impacts, and BRiDGE2Students—that each support our mission. BRiDGE2Science presentations are traditional science talks that are cosponsored by a hosting academic



A poster describing the BRiDGE program hangs in the Department of Geosciences at the University of Massachusetts Amherst beside flyers announcing invited speakers who participated in the department's weekly seminar series. Credit: Benjamin Keisling

department and embedded into that department's regularly scheduled seminar series. BRiDGE2Impacts presentations are events such as talks, workshops, or panels in which the invited speakers, or BRiDGE Scholars, choose the topic and structure for their discussion and share how they use science to make an impact in their community. BRiDGE2Impacts events have sparked conversations about racial justice in affordable housing, navigating academia as a single parent, supporting underrepresented undergraduate students in research programs, identifying our hidden privileges, and other topics. BRiDGE2Students events involve a mentoring lunch that connects underrepresented postdocs and graduate students from different disciplines with successful scientists who share some of their identities and experiences. BRiDGE2Impacts and BRiDGE2Students events have been widely attended by members of many different departments and programs.

We are conscious of cultural taxation, which is the unique burden placed on faculty from marginalized groups at predominantly white institutions of doing excess (often unrewarded) work to promote diversity and inclusion [*Padilla*, 1994], so we provide BRiDGE Scholars with additional professional development benefits. In designing these benefits, we considered some of the reasons that early-career and minoritized scientists are not invited to speak in seminar series, including their "speaking ability" being unknown to faculty nominators. In response, we offer visiting scholars the opportunity to have their science talk filmed and put online to provide an example of their speaking ability. In addition, BRiDGE Scholars have the option to be featured on student podcasts, and students write summaries and reflections of each BRiDGE2Impacts presentation for our website, so the extra effort put in by the scholar is celebrated, documented, and searchable.

Through our efforts, BRiDGE has become a recognized brand on campus, and with 14 scholar visits completed as of this past spring and several more planned, we are creating prestige around the title of "BRiDGE Scholar" within our wider community.

Encouraging Broader Change

We have been developing ways to measure the impact of the program at UMass Amherst, including with surveys of BRiDGE Scholars and seminar attendees. The first barrier to this effort was a lack of existing data with which to compare our survey results because our departments do not collect data about the impacts of their seminars. This year, however, a university-approved plan created by BRiDGE committee members to quantify the impacts of BRiDGE Scholar visits is under way. We are also continuing to collect quantitative survey data about the program.

The response from students who have attended BRiDGE seminars has been positive. One anonymous respondent wrote, "It was such an empowering and rejuvenating experience to hear the BRiDGE lecturer discuss her personal experience with developing her career as a researcher. It really helped me to put my personal growth as a scientist in perspective.... As a woman in science, I felt like a lot of [the] personal struggles of the lecturer and the students resonated with me, but I think anyone, regardless of background, would benefit a lot from discussions like this."

Considering the success of BRiDGE so far, we believe that other departments and programs could undertake similar initiatives to increase diversity, equity, and inclusion (DEI) and better serve the next generation of geoscientists. In fact, one past BRiDGE Scholar, Paula Welander, a microbiologist and associate professor of Earth system science at Stanford University, has since started a similar program there. "By inviting early-career, minoritized faculty to give both a departmental seminar and a broader impacts seminar, we are able to highlight the scientific and societal impacts diverse scientists can bring to the table," Welander said. "And because invited departmental seminars are often viewed as an honor or privilege, we send a very important message to our community about who we value as scientists and experts in our field."

Considering the success of BRiDGE so far, we believe that other departments and programs could undertake similar initiatives to better serve the next generation of geoscientists.

Here are five ways to improve your program's seminar series:

1 Look at who is invited to give seminars, and set goals for increasing diversity. These goals should be guided by demographic data about your department and its invited speakers and by considering how students and early-career scientists in your department could benefit from exposure to scientists who reflect parts of their identity and experience.

2 Broaden the networks you rely on to identify candidate speakers. Professional networks often comprise individuals with similar academic and career trajectories. In the geosciences, most networks of faculty and professional researchers are overwhelmingly white and male. Allowing students to nominate speakers they want to hear from is a way to tap into different networks. Another way to broaden and diversify scientific

networks is to form meaningful relationships with affinity organizations, such as the National Association of Black Geoscientists, the Society for Advancement of Chicanos/Hispanics and Native Americans in Science, the National Organization of Gay and Lesbian Scientists and Technical Professionals, the International Association for Geoscience Diversity, and the Earth Science Women's Network.

3 Invite diverse speakers to your seminar series. In our experience, members of underrepresented groups continue to be overlooked as potential seminar speakers because no one has previously taken the initiative to invite them. Break this cycle by committing your department to inviting seminar speakers who claim one or more marginalized identities.

4 Provide dedicated spaces and times for students to engage in conversations with visiting scholars. Such opportunities are especially important for underrepresented students, who are unlikely to see their identities or experiences reflected in the faculty of their own department, to get career advice, recommendations, and feedback from people who have faced personal and professional obstacles relevant to their own experiences. Furthermore, early-career scholars often bring different institutional and experiential perspectives that can help students navigate challenges they face at their home institutions.

5 Encourage seminar speakers to spend 5–10 minutes during their presentation to discuss how their science affects communities they serve. In a time when many scientists are increasingly seen as untrustworthy by large segments of the U.S. population, it is important for scientists to explain how their work benefits society. Such discussions also help people understand the underlying purposes of a scientist's research and help to engage people from different disciplines during seminar talks.

Many institutions today are declaring commitments to improving DEI. Yet despite their good intentions, acting on those commitments remains challenging. We believe we were successful in developing BRiDGE because we acted on our values and focused on making small changes with big impacts. We challenge all members of the geoscience community to be proactive, intentional, and creative when thinking about the roles they can play in supporting and advancing DEI goals. Instead of waiting for solutions to come from someone else, why not take a chance at building something tailored to your program's needs?

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All Hands on Deck for Ionospheric Modeling

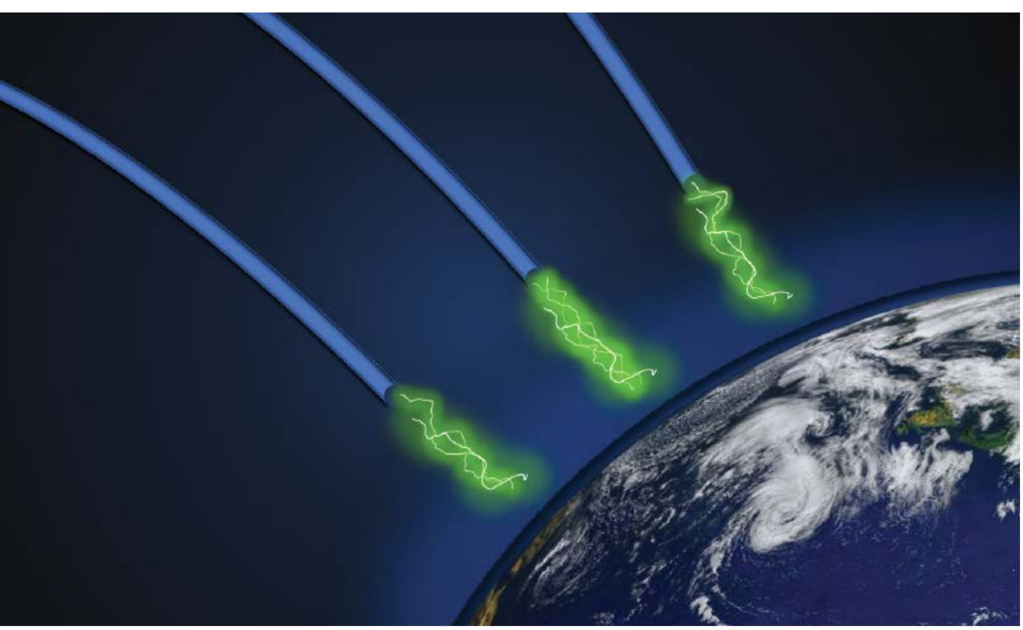
The ionosphere, the ionized layer of Earth's atmosphere far above the stratosphere, plays vital roles in many applications of modern technology. Radio signals travel through the ionosphere, for example, as do some spacecraft. Space weather events that direct energetic charged particles and radiation from the Sun toward Earth interact with the ionosphere, and even moderate space weather events can cause ionospheric conditions to change substantially. These changes affect the reliability of systems integral to society, such as GPS, telecommunications, power grid distribution, and even pipelines that transport oil, gas, and water (by causing corrosion of the pipes).

Ionospheric conductance—the ease with which electrical currents driven by space weather processes travel through the ionosphere—controls how severe the impacts of such events can be [*Harel et al.*, 1981]. Without a thorough and systematic understanding of ionospheric conductance, which can vary spatially and over time, it is not possible to forecast and mitigate resulting disruptions. The challenges of achieving this understanding are too complicated for individual scientists or research groups to confront alone, so we need community-wide engagement.

We now have an opportunity to launch a collaborative forecasting effort to facilitate the protection of critical infrastructure, national security assets, and the safety of civil aviation. In January, the U.S. House Committee on Science, Space, and Technology approved the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act, which entails establishing an interagency working group on space weather forecasting.

We have an opportunity to launch a collaborative space weather forecasting effort to facilitate the protection of critical infrastructure, national security assets, and the safety of civil aviation.

Under this legislation, which is currently awaiting consideration by the full House of Representatives, roles and responsibilities would be assigned to various government agencies and departments as they work together on improving space weather research and forecasting.



Magnetic field lines carry charged particles to Earth's ionosphere, where the particles can interfere with telecommunications, navigation systems, and other technologies. Credit: Doğacan Su Öztürk, JPL/California Institute of Technology

Challenges of Modeling Ionospheric Conductance

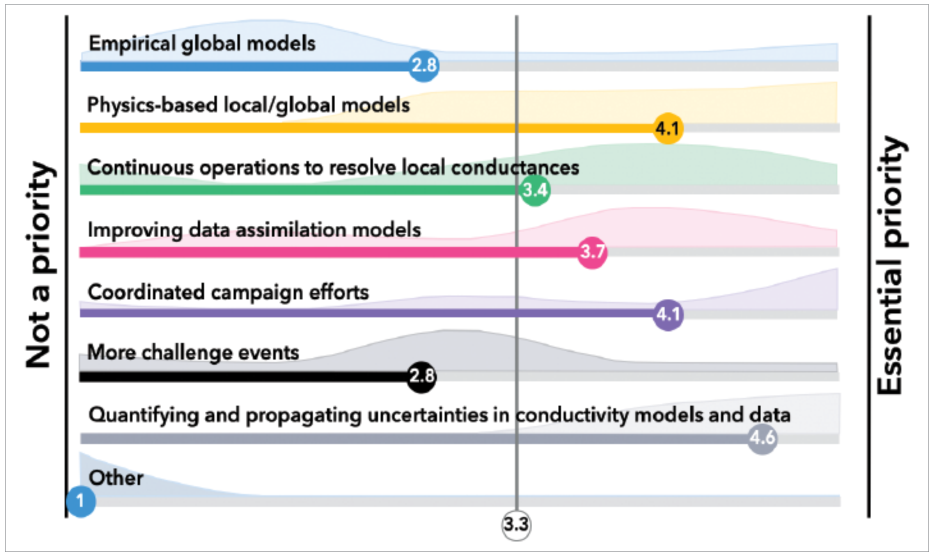
A validation-related focus group has been an integral part of the National Science Foundation (NSF) Geospace Environment Modeling (GEM) community since 2005. As of 2019, Methods and Validation (M&V) became a standing committee to help guide and support various modeling efforts. The focus group held the Ionospheric Conductance Challenge session at the mini-GEM meeting in December 2019 to solicit community input on the biggest challenges faced by researchers working to understand ionospheric conductance. Researchers identified challenges in three major categories in this open-format discussion: a lack of ground truthing, a lack of collaboration, and a lack of funding.

"Ground truth" often refers to information obtained by direct measurements rather than from simulations. Having a designated ground truth data set is a critical component of validating and verifying physics-based models, calibrating instruments, and interpreting observed or simulated phenomena. However, because ionospheric conductance cannot be directly measured, researchers use measurements of other variables, statistical averages, and physical approximations to provide conductance estimates [*Richmond and Maute*, 2014]. These procedures introduce serious uncertainties into the final estimates because the proxy data sets used are sometimes incompatible with each other (e.g., measurements may not have been taken at the same locations or times) and often are limited in spatial and temporal coverage.

Studies of ionospheric conductance involve tools and methods from various research areas that are traditionally separated. Rewarding prosperous collaborations and the exchange of expertise among these different groups are essential to moving the field forward. Interactions should be facilitated and encouraged between modelers and instrument scientists, between empiricists and first-principles modelers, between researchers who study the ionosphere and those who

study the magnetosphere, and between physicists who study neutral particles and those who study plasmas. In the past, joint workshops between the GEM and NSF Coupling, Energetics and Dynamics of Atmospheric Regions communities have helped significantly in bringing together these communities, but further opportunities are needed.

Recognition of ionospheric conductance as a focused science objective is the most effective way to encourage the large-scale and cross-disciplinary collaboration needed to advance data-model validation efforts. Without this agency-level focus, at present, individual research groups study ionospheric conductance in different regions or under different drivers, with only the techniques and measurements already available to them. Therefore, determining conductance values and patterns often emerges as a side problem as researchers focus on more feasible scientific objectives in grant applications. Consequently, many researchers end up having insufficient resources to take on the challenges of studying conductance and have difficulty finding suitable collaborations to help them further their work.



Participants in the Ionospheric Conductance Challenge session were surveyed about their views on where collective effort should be invested to address the most pressing challenges facing ionospheric conductance research.

High-Priority Tasks to Meet the Challenges

In the Ionospheric Conductance Challenge session last December, participants identified three high-priority tasks for the community: quantifying uncertainties, coordinating efforts, and improving models.

The highest priority that the group identified is the need to systematically quantify uncertainties in the different conductance models and data sets available. The NASA Community Coordinated Modeling Center (CCMC) and the GEM M&V focus group are in ideal positions to lead such a cross-disciplinary effort. The M&V focus group organizes Ionospheric Conductance Challenge sessions at the GEM workshops, which provide a great venue for researchers to share their findings and form new collaborations. The CCMC provides online tools for a variety of different numerical models in addition to a data-model database for space weather events designated by the M&V focus group. Through this database, researchers can exchange measurement data and model results. Such platforms expedite uncertainty quantification and provide a basis for validation and verification processes.

Another high-priority task is to compile a list of “challenge” or “campaign” events—space weather events for which there are multiple data sets available and space weather–studying spacecraft in ideal positions to observe—that researchers can work on to better detail ionospheric conductance profiles. Tackling this challenge will require coordinated efforts and extensive input from researchers across a range of institutions and scientific fields. The M&V focus group aims to provide researchers with tools to better understand ionospheric conductance while increasing community engagement and collaboration through these coordinated efforts. Such studies pave the way for identifying the specific observational and computational requirements for improving our theoretical understanding.

The third high-priority task identified is to advance global and local physics-based models of conductance. The theoretical understanding achieved with these efforts benefits the public in the form of improved operational tools, in this case, space weather forecasting models. These models cannot be advanced without systematic validation and verification efforts that require ground truth, collaboration, and funding.

A Path to Progress

When ionospheric conductance is recognized as a key science topic, the community can make substantial progress in improving space weather forecasting models. Targeted solicitations and funding opportunities that foster collaborations between federal agencies, academia, and commercial companies will provide researchers with the resources they need. These steps are crucial for meeting the need for accurate, predictive ionospheric conductance modeling, which has long been a challenge in space weather forecasting.

Acknowledgments

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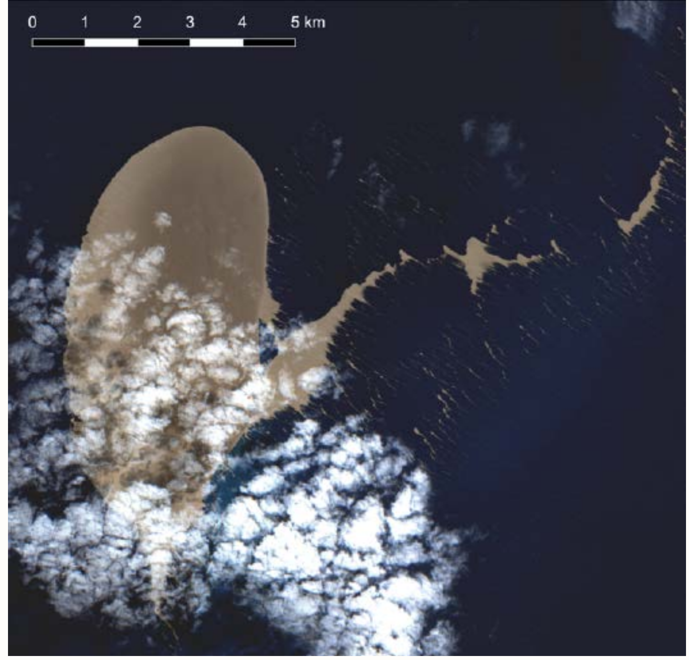
Detecting Underwater Eruptions Through Satellite Sleuthing

By Philipp A. Brandl

Scientists located the volcanic source of a pumice raft floating in the South Pacific Ocean using data from low Earth orbit, illustrating their promise of finding and monitoring undersea eruptions.

In August 2019, news media reported a new pumice raft floating in the territorial waters of the South Pacific island kingdom of Tonga. This visible evidence of an underwater volcanic eruption was borne out by seismic measurements, but conditions were less than ideal for using seismic sensors to precisely locate the source of the eruption. My colleagues and I eventually traced the source of the pumice raft to a submarine volcano referred to as Volcano F using a combination of satellite and seismic data (Figure 1), demonstrating remote sensing's potential for locating and monitoring underwater volcanoes [*Brandl et al.*, 2020].

A pumice raft made of buoyant volcanic rock floats in the Pacific Ocean in 2006. Last year, another pumice raft was spotted in the South Pacific, its origin traced to an underwater volcano with the help of satellite observations. Credit: Fredrik Fransson/Science Photo Library



On 21 August 2019, this pumice raft close to the Exclusive Economic Zone border between Fiji and Tonga was visible from space. Satellite data, combined with seismic readings, helped locate the undersea volcano that was the source of the pumice. Credit: European Space Agency, Copernicus Sentinel-2, CC BY-SA 3.0 IGO (bit.ly/ccbysaigo3-0)

Volcanoes that breach the sea surface often provide clues to impending eruptions, and the events during and after eruptions demonstrate the hazards that marine volcanoes can pose to communities nearby. For example, after several months of growth, a large sector of the south flank of Anak Krakatau, a volcanic island situated in the Sunda Strait of Indonesia, suddenly collapsed into the sea on 22 December 2018. The resulting tsunami killed more than 430 people in nearby coastal areas of Java and Sumatra; it also injured 14,000 people and displaced 33,000. This cascade of events was not totally unexpected because the part of the island above water was clearly visible and was being monitored [*Walter et al.*, 2019].

Unlike events above the sea surface, landslides, earthquakes, volcanic eruptions, and other geological events below the surface are seldom observed as they are happening, but they can also wreak havoc on vulnerable coastal communities. Despite the hazards they pose, assessing the natural hazard risk and mitigating the aftereffects of submarine events remain major challenges. In many cases, the events themselves are hidden beneath the water, and only their direct aftermaths are visible. Recent advances, especially in remote sensing techniques, may enable scientists to identify potential underwater hazards and areas at risk in the near future.

The Challenge of Underwater Eruptions

Landslides and earthquakes are particularly hazardous when they occur not as isolated events but as parts of cascading natural disasters. When these events occur underwater, the disaster might not be evident until it is well under way. Landslides can be directly located only if they are associated with seismicity or are not exclusively submarine. And although global seismic networks can precisely locate earthquakes, determining the details of fault motion, which can influence whether quakes trigger subsequent hazards like tsunamis, requires knowledge of the local seafloor geology and tectonic structure.

Mapping the seafloor for potential hazards will remain challenging because water rapidly absorbs the electromagnetic waves that are key to the satellite remote sensing methods used to map land surfaces. In most cases, submarine volcanic activity thus stays obscured. This is especially true if an eruption is effusive rather than explosive or if an eruption does not breach the sea surface to produce a detectable volcanic gas plume in the atmosphere.

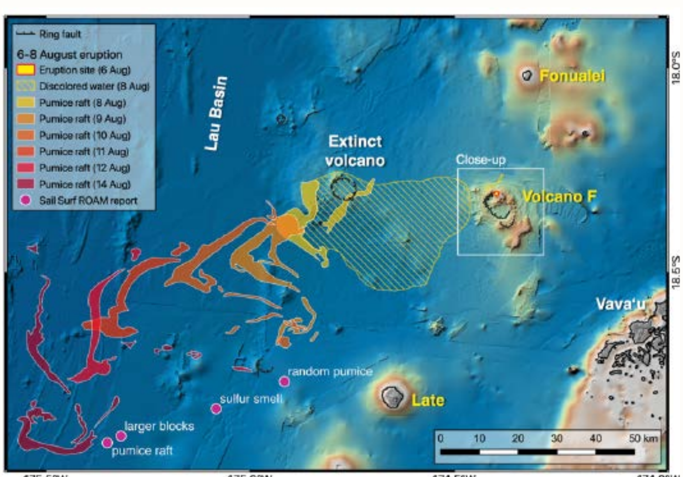


Fig. 1. The drift of the pumice raft between 8 and 14 August 2019 following the 6–8 August eruption at Volcano F. Dots represent locations of pumice on the sea surface and other observations reported by the ROAM catamaran.

Visible eruptions from submerged volcanoes are the exceptions. These include silicic eruptions at island arcs, which are often explosive and eventually eject matter into the air. They also include eruptions of pumice, a highly porous, low-density abrasive volcanic rock that can float on the sea surface [*Carey et al.*, 2018]. Large volumes of pumice can aggregate into rafts that drift with the wind, waves, and currents and present hazards for ships. But these rafts also provide clues to recent submarine eruptions.

Scientists currently rely on in situ methods to track floating pumice rafts, but improved Earth observations from space, coupled with automated image analysis and artificial intelligence, could further enable tracking, ultimately allowing us to trace them back to their volcanic sources if weather permits.

Sourcing the Tonga Pumice Raft

During the August 2019 eruption that produced the pumice raft near Tonga, two stations of the global seismic network located far out in the Pacific Ocean on the islands of Niue and Rarotonga recorded T phases, low-frequency sound waves related to submarine volcanic eruptions. Under ideal conditions, such seismoacoustic signals can be transmitted over very long distances because they couple into a specific layer of the ocean water column, the sound fixing and ranging (SOFAR) channel, which acts as a guide for sound waves. Sound waves reach their minimum speed within the SOFAR channel, and these low-frequency sound waves may travel thousands of kilometers before dissipating. T phases from the 2011 submarine eruption of the Monowai volcanic system, for example, were transmitted in the SOFAR channel over more than 15,000 kilometers.

However, under less favorable conditions, seismoacoustic signal transmission may be more limited. The Tonga Ridge is one example of where such unfavorable conditions prevail because the ridge sits in shallow water and breaches the surface in some places, thus blocking seismoacoustic signal transmissions in some directions. During the

Ship-based multibeam mapping of submarine volcanoes can help constrain eruption dynamics and volume and help monitor morphological changes of volcanic edifices during or after an eruption.

August 2019 eruption, it was not possible to use triangulation to define the precise location of the source, because only two stations recorded the relevant T phases. This difficulty clearly emphasizes the need for increased sensitivity of the global seismic network in this part of the world, which is particularly important with respect to submarine natural hazards.

Seismoacoustic signals may be directly linked to an active submarine eruption, but seismic precursor events may also hint at increasing activity within a volcanic system. In the case of the 6–8 August eruption of Volcano F, eight earthquakes of magnitude 3.9–4.7 were detected in the vicinity of the volcano in the days and hours prior to the eruption. However, given the tremendous amount of seismic activity in this area and the related mass of data under normal conditions, events of this scale usually trigger interest only when followed by a larger and more significant geohazard.

Thus, submarine volcanic eruptions may go unnoticed unless boats and ships report encountering pumice rafts or surveillance flights report visual observations of eruption plumes. In this respect, recent advances in the quality, quantity (e.g., daily coverage), and availability (e.g., the open-source data of the European Union's Copernicus program) of satellite observations have greatly improved our ability to visually detect ongoing volcanic eruptions and their immediate aftermaths, thus representing an important addition to monitoring capabilities. Satellite data may include, among other things, visual observation of the sea surface and spectral detection of volcanic gases or temperature variations in the atmosphere.

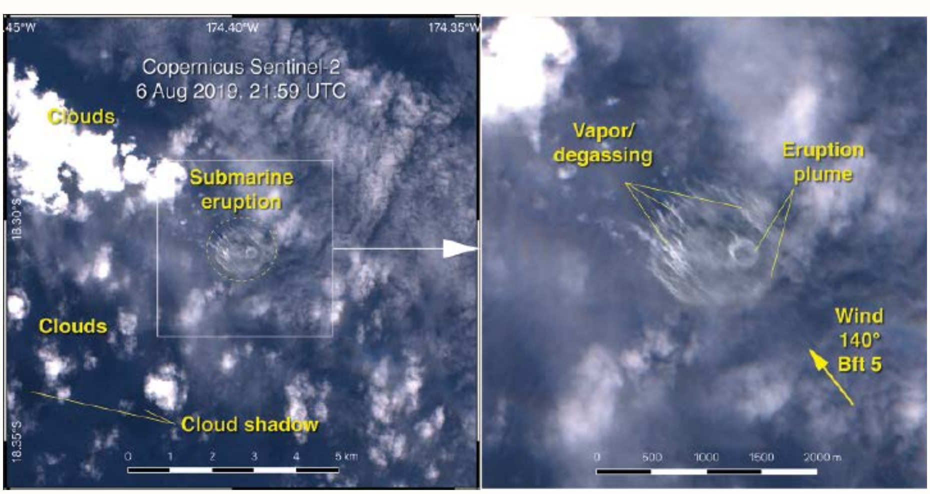
The European Space Agency's (ESA) Sentinel-2 satellite, for example, captured a plume of discolored convecting water, volcanic gas, and vapor about 1.2 kilometers wide coming from the shallow submarine eruption of Volcano F. By combining data from Sentinel-2, available through Copernicus, and from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) system, we tracked the daily dispersal and drift of the related pumice raft.

Gathering Data from Many Sources

Because these satellite techniques are restricted to studying the sea surface, we may still miss many volcanic eruptions in the deep sea. Only hydroacoustic techniques deployed from ships or autonomous underwater vehicles (AUVs) are capable of surveying the ocean floor at needed resolutions, so increased marine research focused on rapid response to submarine eruptions and landslides could strengthen our ability to predict potential natural hazards in the deep sea.

Ship-based multibeam mapping (which can achieve resolutions down to about 15 meters) of submarine volcanoes can help constrain eruption dynamics and volume and help monitor morphological changes of volcanic edifices during or after an eruption. And developments in robotic technology for seafloor mapping, such as autonomous surface vehicles and improved AUVs, which could extend resolution to less than 1 meter, may soon lead to significant advancements in our marine remote sensing capabilities. But currently, the limited coverage of these techniques (less than about 30% of the ocean floor has been mapped by ship-based multibeam sonar) means that only a few areas exist where repeated multibeam surveys allow us to analyze changes in bathymetry over time.

Several segments of the East Pacific Rise, the Galápagos Spreading Center, and the Juan de Fuca Rise are examples of areas where detailed bathymetric maps have been used to monitor volcanic activity. In the southwestern Pacific, well-mapped



This satellite imagery shows the sea surface on 6 August 2019 following the eruption of Volcano F. Abbreviations are UTC, coordinated universal time; Bft 5, Beaufort scale category 5 winds, corresponding to 29–38 kilometers per hour. Credit: European Space Agency, Copernicus Sentinel-2, modified by Philipp Brandl

areas include arc volcanoes such as those in the Tofua-Kermadec Arc, the Monowai Volcanic Center, the Havre and Brothers volcanoes, and West Mata. Repeated phases of growth and partial collapse of the edifice of the Monowai arc volcano have been well monitored [*Watts et al.*, 2012]. However, this level of monitoring has been possible only through repeated bathymetric surveys (1978, 1986, 1998, 2004, 2007, and 2011) that together integrate to an important time series.

During a cruise in 2018, my colleagues and I "accidentally" mapped the flanks of Volcano F (it was not the focus of our cruise). By combining our data with preexisting data from an Australian cruise, we created a combined bathymetric map (Figure 2) that could serve as a basis for identifying future changes in bathymetry due to volcanic activity [*Brandl et al.*, 2020].

At present, the risk potential of cascading events in the submarine realm is poorly understood, mainly because of the lack of data and monitoring. Studies like those described above would be of great value in assessing the risks of cascading natural disasters elsewhere—for example, at the many arc volcanoes whose edifices are composed of poorly consolidated volcaniclastic material rather than solid masses of rock. Volcanic growth can lead to a buildup of material that if followed by partial sector collapse, can trigger a tsunami—this was the case at Anak Krakatau in 2018.

Emerging technologies such as artificial intelligence and machine learning could fill an important gap. Proactive automated processing of data from global seismic networks could help to identify clusters of increased seismicity that could be precursors to volcanic eruptions. The locations and timing of these clusters could then be used to pick out features in hydrophone data from the same times and places that correlate with submarine eruptions. Earth and computer scientists are currently developing techniques for automated image analysis and data processing as well as the use of artificial intelligence for pattern recognition and the proper identification of submarine volcanic eruptions.

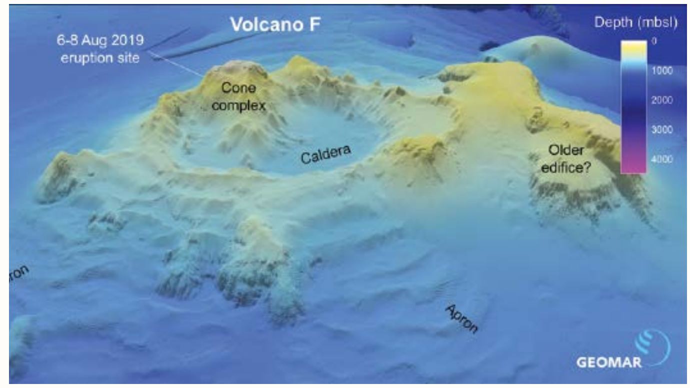


Fig. 2. Composite bathymetry of Volcano F from ship-based multibeam data collected by R/V Sonne *cruise SO267 and R/V* Southern Surveyor *cruise SS2004/11.*

Compiling existing data and collecting new data related to submarine volcanic activity in a dedicated open-access database should help researchers estimate risk potentials as the first step toward forecasting natural hazards.

Moving Beyond Accidental Discovery

Currently, submarine eruptions from island arc volcanoes and mid-ocean ridges are observed mainly by accident or when their eruption products breach the sea surface. Thus, we likely never see a significant proportion of submarine volcanic eruptions. And we lack the ability to monitor submarine volcanic activity on a global scale, which limits our ability to assess risks related to underwater volcanic eruptions, sector collapses, and cascading events.

Remote sensing techniques that collect data from space and at sea may provide us with more powerful tools to detect and monitor this volcanic activity and to project associated risks in remote areas. Recent advances in data processing may also greatly improve capabilities in this field. And compiling existing data and collecting new data related to submarine volcanic activity in a dedicated open-access database should help researchers estimate risk potentials as the first step toward forecasting natural hazards.

The experience with the 2019 eruption of Volcano F shows how important the integration of open-source and interdisciplinary remote sensing data is for the monitoring and management of natural hazards.

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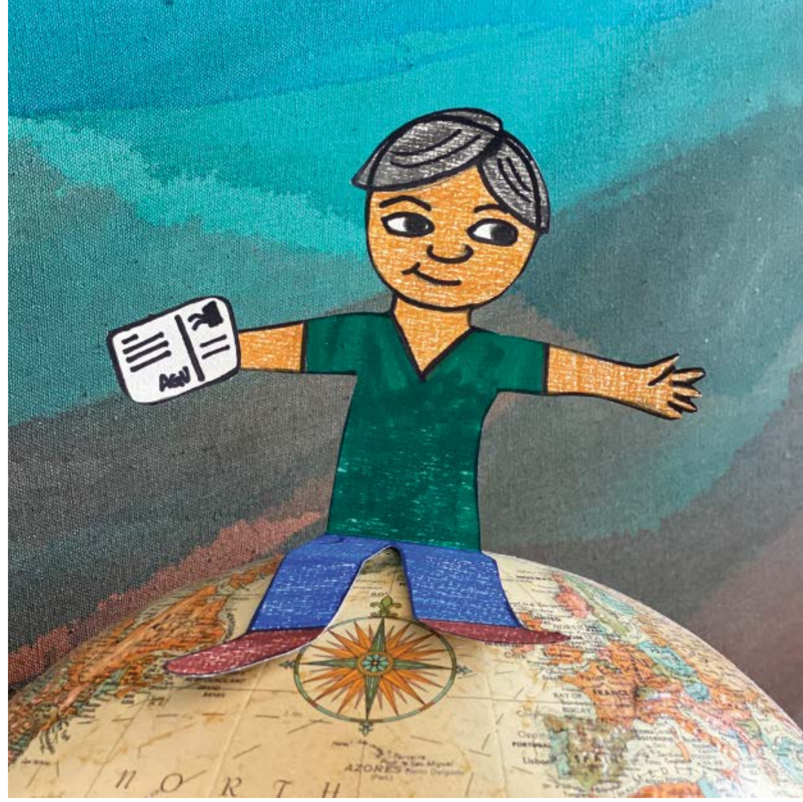

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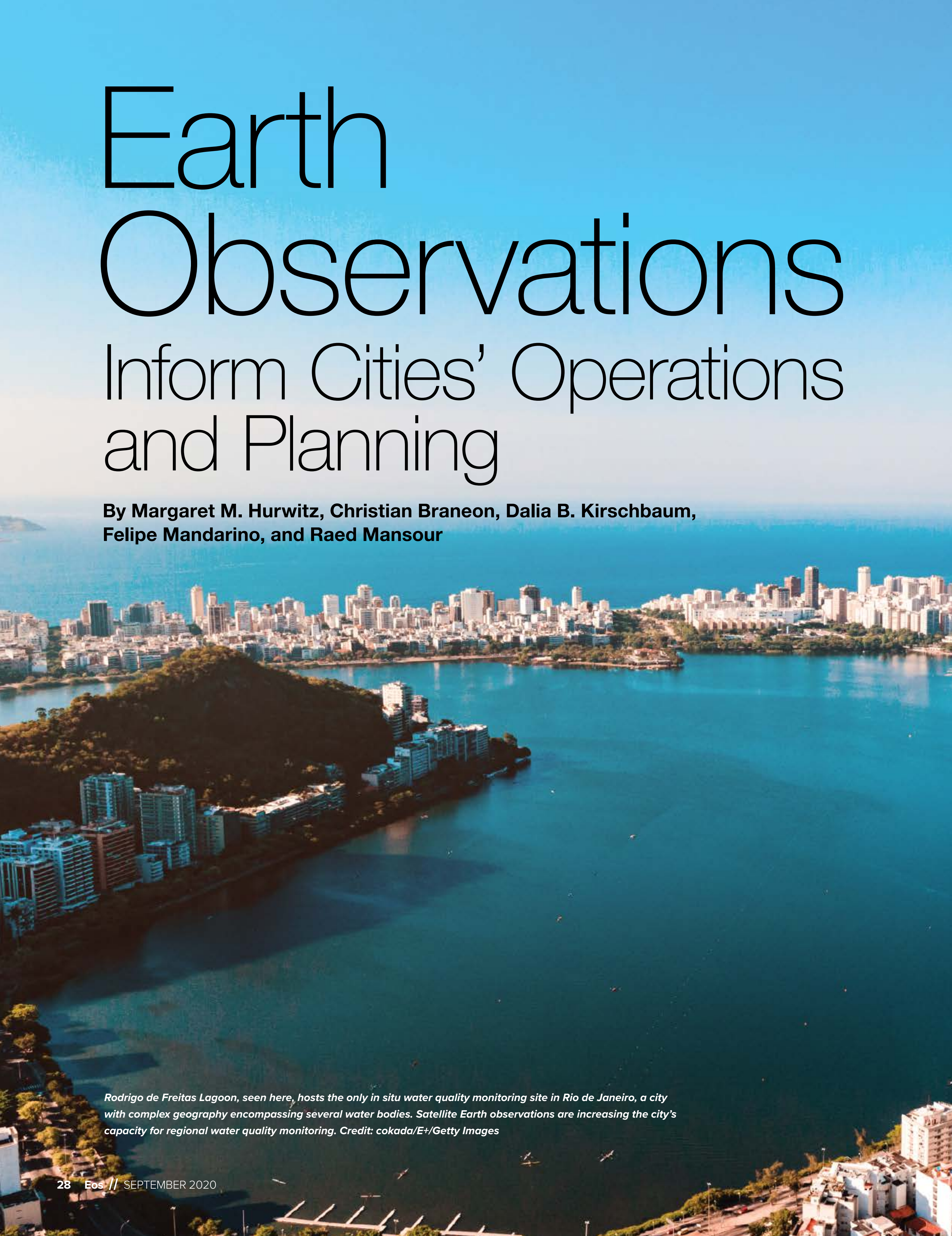
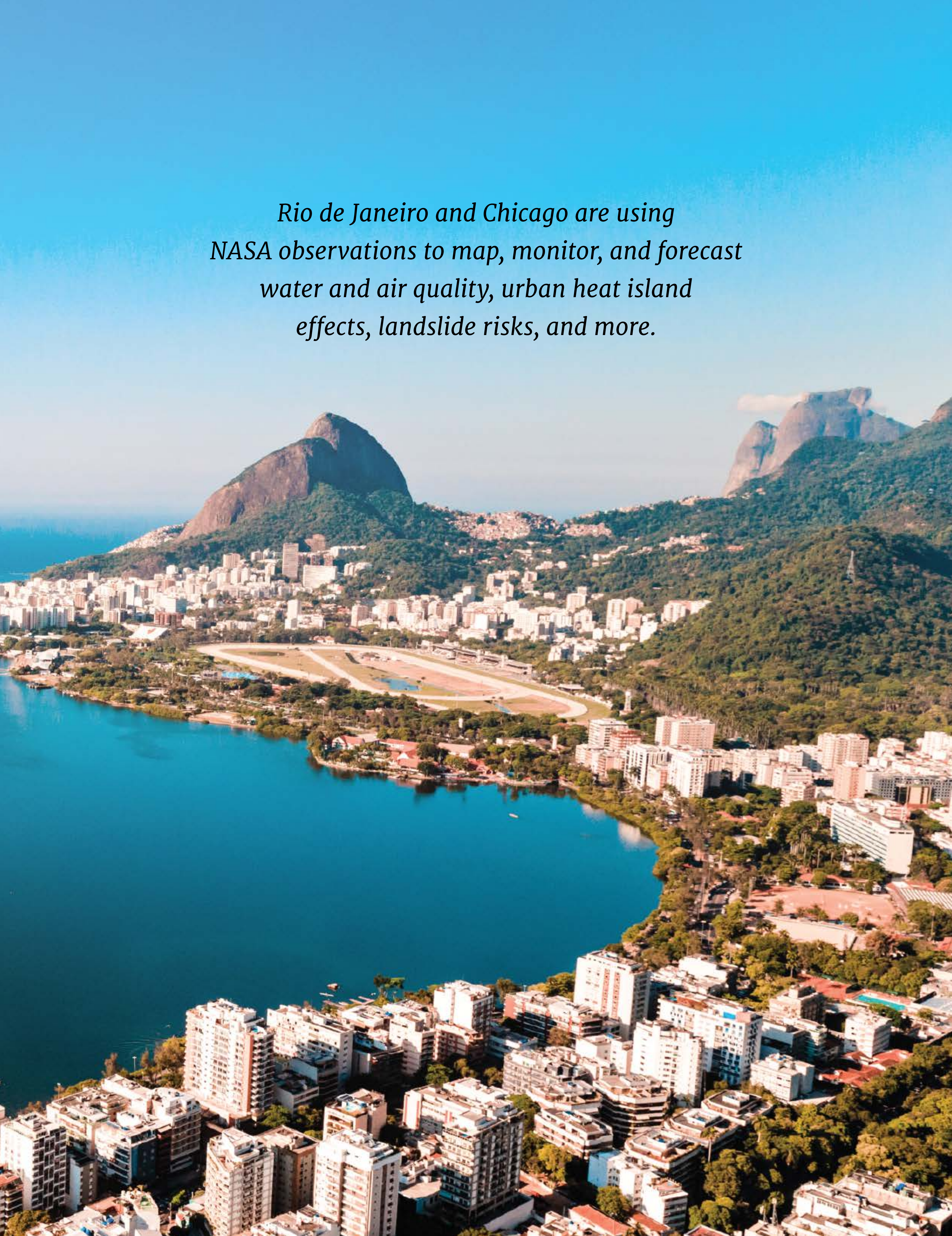
Earth Observations Inform Cities' Operations and Planning

By Margaret M. Hurwitz, Christian Braneon, Dalia B. Kirschbaum, Felipe Mandarino, and Raed Mansour



Rodrigo de Freitas Lagoon, seen here, hosts the only in situ water quality monitoring site in Rio de Janeiro, a city with complex geography encompassing several water bodies. Satellite Earth observations are increasing the city's capacity for regional water quality monitoring. Credit: cokada/E+/Getty Images

Rio de Janeiro and Chicago are using NASA observations to map, monitor, and forecast water and air quality, urban heat island effects, landslide risks, and more.



State-of-the-art Earth observations can be used to map, monitor, and forecast many aspects of the urban environment.

Cities around the world face numerous environmental hazards—extreme heat, flooding, landslides, pollution, and harmful algal blooms, to name a few—that they must monitor and address to reduce risk to their residents. One way to help keep city officials informed about these hazards is to invest in dense urban monitoring networks: arrays of sensors on and in the ground that provide continuous streams of diagnostic data [*Bai et al.,* 2018].

However, in situ monitoring networks by themselves do not provide cities with sufficient information to make sound decisions on either short or long (i.e., climate change) timescales. These networks may struggle to keep up with rapid population shifts or growth, in part because people can quickly migrate across officially recognized city boundaries. And in less developed countries, dense urban monitoring networks are unlikely to be economically feasible or to cover informally settled areas adequately [*Miller and Small,* 2003]. Further, data from these monitoring networks alone cannot predict future environmental conditions.

Meanwhile, the spatial and temporal resolution of satellite-based products and Earth system models is progressively increasing. State-of-the-art Earth observations from these products can be used to map, monitor, and forecast many aspects of the urban environment. Urban-scale remote sensing is increasingly common in the research community [*Creutzig et al.,* 2019]. Likewise, complex Earth system models are being used to understand the evolution of urban environments on longer timescales: The Urban Climate Change Research Network (UCCRN) recently released its second report on climate change in cities [*Rosenzweig et al.,* 2018], for example, and the Intergovernmental Panel on Climate Change is incorporating an urban research agenda into its next assessment cycle.

In light of the increasing proportion of the global population that lives in cities [*United Nations,* 2019], the shared goal of making cities “inclusive, safe, resilient and sustainable” espoused in the United Nations’ Sustainable Development Goals, and the availability of high-resolution data sets [*Ilieva and McPhearson,* 2018; *Creutzig et al.,* 2019], it is now feasible and advantageous for cities to factor Earth observations into their environmental decision making.

Two early-adopter cities, Rio de Janeiro, Brazil, and Chicago, Ill., are already integrating Earth observations from NASA into their planning and operational decision making. The city of Chicago is working with NASA and other collaborators to assess urban air quality and understand the city’s urban heat island. The NASA–Rio de Janeiro Partnership, a formal partnership between NASA’s Earth Science Division and Rio de Janeiro’s city government, began in 2015 with the goal of enhancing the city’s resilience to natural hazards and climate change through joint projects.

A Comprehensive View

Compared with observations from the typically limited number of monitoring stations in cities, Earth observations from remote sensing–based products provide a broader and more comprehensive picture of urban environmental features [*Famiglietti et al.,* 2015]. In Rio de Janeiro, for example, a coastal city with complex geography encompassing several water bodies, a single

A view across Montrose Harbor in Chicago. The city of Chicago is working with NASA and other collaborators to assess urban air quality and understand the city's urban heat island. Credit: Raed Mansour,

in situ monitoring site at Rodrigo de Freitas Lagoon provides water quality data, including chlorophyll levels (an indicator of algal blooms) and total suspended solids (an indicator of sediment levels). However, combined Landsat-Sentinel maps of these water quality indicators [*Pahlevan et al.,* 2019] have greatly enhanced Rio de Janeiro's capacity for regional water quality monitoring. The usefulness of these maps has prompted the city to share the data beyond its administrative boundaries, which has, in turn, strengthened Rio de Janeiro's relationships with other cities sharing its coastline, such as Niterói.

Earth observations can also fill gaps when local information is not available. Although Rio de Janeiro has eight fixed air quality monitoring stations, as well as a mobile monitoring station, the city does not have access to local air quality forecasts. Through the NASA–Rio de Janeiro Partnership, the city has been testing NASA's Goddard Earth Observing System (GEOS) Chemical Forecast system, which is providing city officials daily with 5-day forecast maps of nitrogen dioxide, ozone, and other key air pollutants.

Tailoring Products for Local Needs

Decision support tools based on Earth observations can be tailored to meet cities' specific needs and geographies. For example, landslides are a major hazard for people living on steep slopes in Rio de Janeiro. The city has implemented a customized version of NASA's Landslide Hazard Assessment for Situational Awareness (LHASA) [*Kirschbaum and Stanley,* 2018], which, combined with knowledge of the region's history of landslides, has enhanced the city's ability to identify potential landslide activity during and after rain events.

The LHASA-Rio system integrates information from the city's 33 automatic weather stations, including rain gauge data, with a landslide susceptibility map at 5-meter spatial resolution to generate a map of potential landslide activity in near-real time. Since November 2018, the LHASA-Rio system has been identifying potential landslide activity in the most vulnerable areas of the city and communicating these through the Alerta Rio public alert system.

In cities with high technical capacity, off-the-shelf Earth observations can be incorporated directly into city monitoring efforts. The Chicago Department of Public Health, with support from local academic partners, has combined open-source measurements to produce baseline air quality, weather and climate visualizations, and localized models at the neighborhood level. These measurements come from such sources as Array of Things temperature sensors, local emissions inventories, and remote sensing products from satellite instruments like the Moderate Resolution Imaging Spectroradiometer (MODIS).

A dashboard tool that combines measurements of key air pollutants with the variables that influence air quality, such as traffic emissions and land cover, is in development (Figure 1).

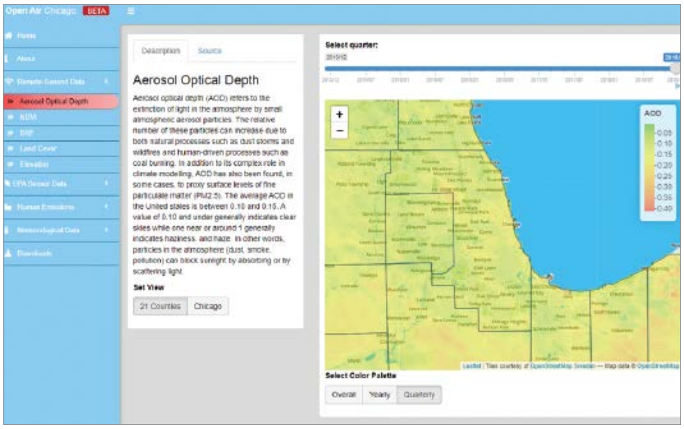


Fig. 1. This view of the Open Air Chicago dashboard shows an aerosol optical index map for the city of Chicago and surrounding areas.

Fig. 2. Areas of Rio de Janeiro most vulnerable to sea level rise (SLR) by 2080 are shown here shaded in yellow, orange, and red, corresponding to land elevations, from a NASA–Rio de Janeiro joint study that combined local measurements, a lidar survey of city topography, satellite altimetry data from TOPEX/Poseidon and the Jason missions, and CMIP5 climate projections.

This tool will help the city of Chicago to analyze its operations, model the impacts of projected environmental changes on the city's air quality, and facilitate the collaborative development of air pollution interventions by city agencies, researchers, and community stakeholders.

Building Urban Resilience

Local data can be combined with climate projections and scientific expertise to enhance cities' resilience to climate change [*Urban Climate Change Research Network*, 2018]. Researchers involved in a joint NASA–Rio de Janeiro study identified areas in the city most vulnerable to sea level rise by 2080 (Figure 2) by combining local tide gauge measurements, a lidar survey of city topography, and satellite altimetry data from TOPEX/Poseidon and the Jason missions with Coupled Model Intercomparison Project 5 (CMIP5) climate projections. A map of Rio de Janeiro's urban heat island, created using Landsat-based land surface temperature data, similarly informed the city's climate adaptation plans for heat mitigation.

In Chicago, city officials are working with NASA scientists to better understand the temporal and spatial evolution of the city's urban heat island. As a result of a 2016 workshop, Chicago's Department of Planning and Development launched a pilot program to use NASA Earth observations in its climate adaptation planning, drawing on input from Microsoft and NASA.

The program will identify the hottest areas in Chicago for further analysis, test the effects of the city's heat mitigation policy interventions, and create a baseline for future urban planning. One pilot project in this program leverages NASA remote sensing data sets to generate heat maps for cities; another studies historical data to determine how changes in surface temperatures were related to urban planning policies.

Synergy Between Cities and Product Developers

Strategic project selection in Chicago and Rio de Janeiro has generated beneficial scientific collaborations. The selected projects are advancing scientific understanding, particularly with respect to testing new data products and validating satellite data sets, and they are meeting the needs of the city governments.

For example, testing the GEOS-Chemical Forecast model has provided mutual benefits to both Rio de Janeiro and the NASA model development team. The Rio de Janeiro team provided multiyear air quality station data through an online platform. Comparisons between the air quality forecast model and measurements taken in Rio de Janeiro revealed discrepancies, and efforts to resolve these discrepancies have led to model improvements such as refining the model's local emissions inventories. Scientists from the city's government offered to test a proposed downscaled version of the forecast model, so they were given early access to a tool that incorporates Rio de Janeiro's complex topography. This customized tool could be used in the future to warn residents when the forecast calls for potentially hazardous air quality.

Lessons Learned in Rio de Janeiro and Chicago

Earth observations are enhancing Rio de Janeiro's and Chicago's environmental monitoring and long-term planning capa-

bilities through pioneering applications of remote sensing and model-based products at the urban scale. As described above, Earth observations are particularly valuable in cases where in situ observations are nonexistent or limited. And where in situ observations are available, Earth observations are useful in validating remote sensing products and predictive models. Combining in situ observations and local context with satellite observations leads to powerful products that provide cities with localized, actionable information.

Scientific collaborations with these two cities benefited from the cities' investments of time and resources in joint projects. Strong relationships between researchers and city officials resulted from years of sustained, regular communication. The collaborations also benefited from open data sharing practices—the cities published local data online, and NASA made test versions of new products available to city partners—and from the cities' centralized government structures, which allowed multiple city offices to work toward common goals.

In Rio de Janeiro and Chicago, the cities' high degree of technical capacity has helped the process of integrating Earth observation products into operations. Conversely, many cities' lack of technical capacity is a barrier to the adoption of Earth observation products. Small cities and cities in developing countries may lack the workforce capacity or data infrastructure to store, process, and use Earth observation–based products [*Kansakar and Hossain,* 2016]. Making Earth observation data sets and model outputs easier to download and analyze would greatly facilitate and likely expand their adoption by city governments.

Scientific collaborations with these two cities benefited from the cities' investments of time and resources in joint projects.

Acknowledgments

The authors thank NASA's Earth Science Division for supporting collaborative work with Rio de Janeiro and Chicago. The Open Air Chicago project by the Chicago Department of Public Health and the Center for Spatial Data Science at the University of Chicago acknowledges funding from the Bloomberg Philanthropies Partnership for Healthy Cities, with Vital Strategies as an implementing partner, as well as the technical contributions of J. Koschinsky, I. Kamber, J. Wang, A. Ladoy, Y. H. Park, Y. X. Tan, T. Stephens, A. Laha, and G. Morrison. The authors thank N. Pahlevan and C. Keller for providing descriptions of the Landsat-Sentinel water quality anomaly and GEOS-Chemical Forecast products, as well as their collaborative research with the city of Rio de Janeiro. D. Bader, C. Rosenzweig, T. McPhearson, M. Kolak, R. Pandya, and E. Glenn contributed to this article.

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Eyes in the Sky Improve Pollen Tracking

Physicians, public health officials, and experts in remote sensing and ecology are identifying ways that satellites, webcams, and crowdsourcing could help them manage asthma and allergies.

By Ghassem R. Asrar, Yuyu Zhou, Theresa M. Crimmins, and Amir Sapkota

Every year, plants around the world burst into bloom, producing a spectacular display of color—and releasing an abundance of pollen. For people with asthma and other respiratory ailments, springtime heralds the beginning of a season of misery.

Asthma affects more than 319 million individuals globally. In the United States, nearly 8% of the population currently suffers from asthma, costing more than $80 billion annually in treatment and loss of productivity [*Nurmagambetov et al.*, 2018]. Despite this high health care cost and the real suffering of those with allergies, pollen monitoring in the United States, which could help reduce necessary treatments and lost time, remains limited. However, satellites that monitor plant activity are poised to play a major role in a coordinated effort to generate localized pollen forecasts, which could help millions of people breathe easier.

Pollen Information from Three Sources

The U.S. federal Interagency Working Group on Climate Change and Health concluded that climate change will likely amplify existing environmental triggers of asthma, resulting in more severe and frequent exacerbations, particularly among vulnerable populations [*Portier et al.*, 2010]. Although pollen is one of the leading risk factors known to worsen asthma symptoms, pollen monitoring in the United States is often undertaken by a private network of physicians with no governmental support. Because of the high labor cost associated with pollen counting, there were only 82 National Allergy Bureau–certified pollen counting stations in 2012, translating to one pollen monitor for every 3.4 million Americans.

Recent advances in Earth observations could support human health interventions by addressing the paucity of information on pollen presence, makeup, and concentration. Satellite-borne sensors, such as those on the Landsat missions, have the potential to provide remotely sensed information regarding the annual variability, spatial extent, and seasonality (start, peak, and end) of pollen patterns. Proxy data related to pollen dynamics generated from this information can also be used to identify the onsets and durations of seasons for important types of pollen.

In addition, near-surface images collected hourly from cameras on towers in the PhenoCam Network, currently comprising hundreds of sites worldwide, can

supplement satellite-derived data. The thousands of observations collected and reported on a daily basis by participants in crowdsourcing programs like the USA National Phenology Network's Nature's Notebook program can provide still further information on the life cycle status of plants across the country, verifying information provided by satellite- and tower-based sensors.

These different types of observations are complementary and, combined, offer pictures that are both overarching and locally detailed. Together these resources would also provide more insight than we can currently gather into the taxonomy, or identities, of plants that contribute pollen during different life cycle stages (i.e., greening, flowering, senescing) over the course of the pollen season.

Satellites that monitor plant activity are poised to play a major role in a coordinated effort to generate localized pollen forecasts, which could help millions of people breathe easier.

In particular, our recent work has shown that satellite-based phenology data can reveal information about the likelihood of asthma hospitalization risk at the local level [*Sapkota et al.*, 2020], which is projected to be further exacerbated by climate change. This work highlights the substantial potential benefits of integrating these data sets and delivering information to clinicians, public health practitioners, and the public to improve decisions regarding management of pollen allergy symptoms, especially for vulnerable segments of the population.

Bridging Gaps Between Science and Health

Researchers recently convened a workshop involving physicians who treat allergic diseases, public health officials, and experts in remote sensing and ecology. The goals of the workshop were to assess the poten-

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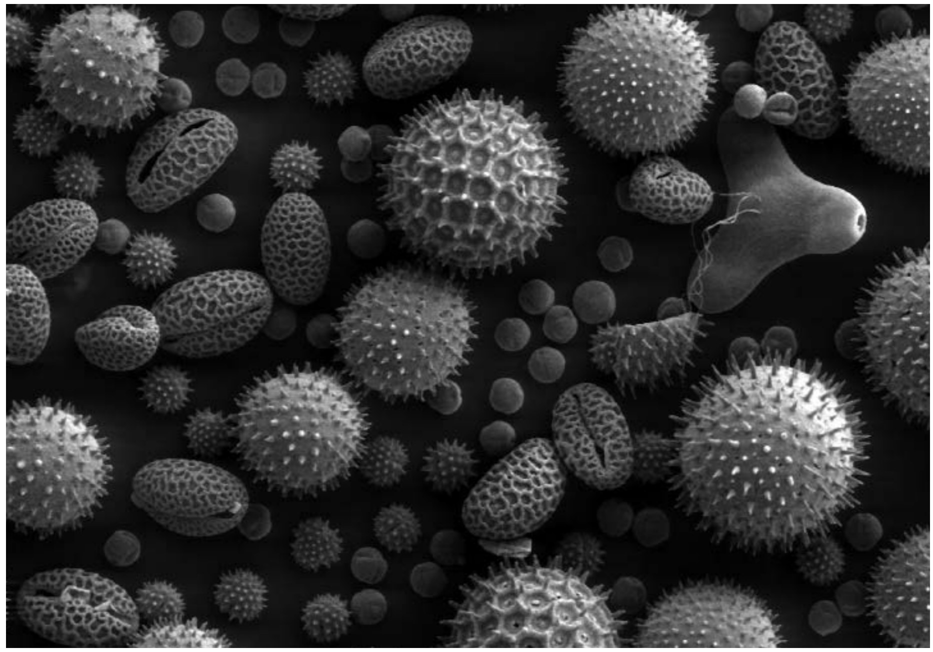
tial to bridge information gaps among scientists, health care professionals, and the public using Earth observations and to gauge interest in joining collaborations to address this multidisciplinary scientific and technical challenge. Participants confirmed their interest in working together and agreed on the need for better information about seasonal pollen patterns, including on the start of pollen season and the timing of peak pollen levels. This information could dramatically improve the timing of advice that clinicians and public health practitioners can provide to individuals suffering from pollen-related allergies and asthma, such as about updating prescriptions, purchasing over-the-counter medications, and modifying outdoor activity.



Pollen from sunflower, morning glory, prairie hollyhock, oriental lily, evening primrose, and castor bean is seen in detail in this scanning electron microscopic image. Credit: NASA Goddard Space Flight Center

Participants also agreed that several important shortcomings exist in currently available information, including the lack of reliable near-real-time pollen measurements and data-driven short-term projections of pollen concentrations for use in advising patients. However, there are opportunities to leverage existing data sources to improve allergy warnings and advisories in the short term (days to months).

First, PhenoCam images and volunteer-contributed, ground-based phenology observations could be used to develop a simple location-specific indicator for the pollen onset and severity. Such an indicator could help fill gaps in pollen information at local to global scales; however, the PhenoCam Network is still evolving and adding new stations, so it may take time before its full potential for generating high-resolution data at a global scale is realized.

Second, existing satellite observations could be leveraged to estimate the start and timing of peak concentrations for the most allergenic taxonomic groups, including trees in spring and, to a lesser extent, grasses in summer and weeds in fall. These estimates would provide health practitioners with substantially more information than is currently available. This capability to obtain reliable pollen information from satellite observations has been demonstrated for birch (*Betula*), a highly allergenic species, and it has the potential to be extended to many more plant species [*Karlsen et al.*, 2008; *Li et al.*, 2019a]. PhenoCam observations and data from pollen monitoring networks and volunteer-based observations are valuable in verifying the efficacy of these space-based observations for deriving phenology indicators and vegetation-specific onset, duration, and intensity of pollen production [*Khwarahm et al.*, 2017; *Li et al.*, 2019b].

Third, determining the drivers of pollen development and release opens the door to producing real-time and short-term projections of airborne pollen for key pollen species. These projections are invaluable to allergy health experts and practitioners and to public health authorities.

Environmental scientists, public health experts, and physicians must work together to incorporate emerging technologies to tackle scientific challenges and improve health and well-being.

Pollen Dynamics and Early Warnings

Supporting the development of early-warning systems requires additional research in several areas. First, we need to develop predictive models for ground-level pollen that leverage satellite data, PhenoCam observations, and crowdsourced phenology data to fill information gaps between sparse pollen monitoring stations. Next, we need to improve our understanding and knowledge of the ways that different pollen types are related to allergic asthma symptoms based on demographics like gender and socioeconomic conditions, especially in rapidly developing urban systems around the world. Likewise, we need to improve our understanding of how pollen may synergistically interact with other known risk factors of asthma—such as air pollution (e.g., from ozone and particulate matter) and extreme heat—to worsen asthma symptoms.

Recent studies demonstrate the feasibility of using satellite-based phenology information together with asthma allergy hospitalization data to derive information useful to allergy health experts, practitioners, and policy makers [*Sapkota et al.*, 2019, 2020]. There is an urgent need to evaluate the efficacy of such an approach for a wide range of systems, environmental conditions, vegetation types, and demographic populations in urban, suburban, and rural settings.

Finally, rethinking clinician education and training experiences can provide additional opportunities to improve patient care related to asthma and allergies. Allergy experts participating in our discussion noted the absence of environmental health topics in medical school curricula. They indicated that this gap impedes efforts to incorporate considerations of environmental change–related hazards and risks in day-to-day patient care.

Science Serving Society

There are many opportunities to use existing technologies and data sets to better anticipate human allergenic responses to various factors in the environment. To ensure healthy people and a healthy planet and in the spirit of science and technology serving society, environmental scientists, public health experts, and physicians must work together to incorporate such emerging technologies to tackle scientific challenges and improve health and well-being.

Through an initial conversation involving public health officials and physicians who treat allergic diseases, we set the stage for progress on developing and delivering more actionable information regarding the risk for asthma and allergic responses in humans. We are excited by the prospects of advancing this multidisciplinary field by bringing together experts in public health, ecology, Earth observations, information science and technology, and crowdsourced science to focus on a critical challenge. We hope to fulfill information needs for public health and to improve quality of life for people around the world who are vulnerable to pollen allergies.

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Social Media Helps Reveal Cause of 2018 Indonesian Tsunami

This extensive damage in Palu Bay, Indonesia, was caused by the 2018 tsunami. Credit: Philip Liu

On 28 September 2018, a magnitude 7.5 earthquake shook Sulawesi Island in Indonesia and triggered a tsunami that pummeled Palu, the provincial capital. The quake and the resulting tsunami, with waves that topped 5 meters in Palu Bay, wreaked extensive damage on one of Indonesia's largest and most populous islands. Ultimately, 4,340 people died as a result of the tsunami, and thousands of buildings were damaged or destroyed.

The region is no stranger to large earthquakes. Eastern Indonesia is characterized by complex tectonics, and Sulawesi rests on the Palu-Koro Fault, a major fault that stretches 220 kilometers. Over the past century, the area has experienced 15 earthquakes with magnitudes greater than 6.5.

Yet the 2018 tsunami event was an oddity. There was no readily apparent mechanism by which the strike-slip earthquake could generate such a massive tsunami, and simulations repeatedly underestimated the inland thrust of the waves that were reported in post-tsunami surveys. Researchers floated two potential explanations—seafloor displacement from the quake and submarine landslides—but sparse instrumental data prevented any firm conclusions about the source of the tsunami.

Borrowing an approach used after the 2004 Indonesia and 2011 Japan tsunamis, *Sepúlveda et al.* supplemented tide gauge data in Palu Bay with a compilation of 43 videos crowdsourced from social media sites like Twitter and YouTube as well as from local closed-circuit television feeds. In previous work, researchers geotagged the specific locations of the videos by matching features visible in Google maps and then used the videos to pinpoint the timing of the tsunami and the corresponding water level at each location. The video-derived sea level time histories served as pseudo-observations where tide gauge data were lacking.

Using the data derived from social media as well as satellite interferometric synthetic aperture radar data, which measures changes in land surface altitude, the authors of the new study tested the two hypotheses of what caused the tsunami using earthquake models. They found that seafloor deformation played only a minor role. Instead, a handful of landslides in Palu Bay proved to be the major contributors to the tsunami.

The 2018 Palu event highlights the shortcomings of using tide gauges alone to document tsunami events, according to the authors, and challenges conventional assumptions about tsunami hazards from strike-slip earthquakes, revealing that landslides caused by strike-slip quakes can produce deadly tsunamis. (*Journal of Geophysical Research: Solid Earth,* https://doi.org/10.1029/2019JB018675, 2020)

—Aaron Sidder, *Science Writer*

Lending a Hand to Sustainability

Over the past 30 years, the concept of ecological footprints has gained traction as a metric for understanding individual and collective impacts on the environment. The term originated in the early 1990s and has grown so commonplace that entities ranging from professional sports leagues to financial institutions use it to understand their resource use. A carbon footprint, for example, characterizes an individual's or organization's carbon emissions.

However, to overcome daunting global sustainability challenges, it is not enough to know that our actions generate negative impacts, argue *Guillaume et al.* in a new study; recognizing humanity's positive contributions is also key to creating a sustainable future. Enter the environmental handprint.

Handprint thinking—initially established about a decade ago—is intended to promote affirmative environmental action and complement the notion of footprints. Whereas ecological footprints can cause counterproductive stress and paralysis, a positive approach reveals opportunities for improvement and clarity on how to act, the authors suggest.

In the study, the authors lay a foundation for evaluating environmental handprints. They establish three core principles of handprint thinking and identify critical questions to address when conducting a handprint assessment. The three principles include encouraging activities with positive impacts, connecting handprint analyses to footprint reductions while adding value to them, and identifying actions to take.

The authors provide a case study examining the annual water footprint of an average individual's food in Finland. This average person eats more meat products than national recommendations suggest and often lunches at a workplace cafeteria. In this context, the authors explored opportunities for action—and trade-offs of choices—by this person, factors influencing the person's capacity to act, and pathways to influence others.

In the example, the authors find that average Finns can reduce their food water footprint by 51%–69%, depending on the stringency of their efforts. Even modest attempts to avoid overeating, reduce meat consumption, and limit food waste can yield substantial gains.

The handprint concept empowers individuals by giving them authority to reduce their environmental footprint. Through their analysis, the authors contribute theory to bolster handprint thinking and practical implications for implementing it in future research and real-world settings. (*Earth's Future*, https://doi.org/10.1029/2019EF001422, 2020) **—Aaron Sidder,** *Science Writer*

Why Did Great Apes Disappear from Southwestern China?

Orangutans are the sole survivors of a major radiation of great apes across Eurasia, from Spain to China, in the Miocene, which began about 23 million years ago. By the late Miocene, most of these species had become extinct, but fossil records show that the Yunnan region of southwestern China continued to harbor great apes well into the terminal Miocene. Why these holdout hominoids eventually disappeared too has been unclear.

Now *Li et al.* have found that from 6.2 million to 5 million years ago, periodic cooling interrupted a generally warm, humid climate in the Yunnan region, potentially triggering changes in vegetation that provided food for great apes and contributing to their disappearance.

Evidence for these cool episodes came from a sediment core collected in an ancient Yunnan lake bed. The core contains materials deposited between 8.8 million and 2.6 million years ago. Analysis of the chemical composition of the sediments at different points in the core revealed evidence of chemical weathering processes that indicate what the climate was like when the different layers of sediment were deposited.

The analysis suggests that conditions were generally warm and humid from 8.8 million to 6.2 million years ago, despite a gradual cooling trend. However, between 6.2 million and 5 million years ago, three pulses of strong climatic cooling occurred amid the warmer background climate. After 5 million years ago, the region's climate continued to cool.

The sediment core was extracted about 500 meters from where the youngest known Miocene great ape fossil—the cranium of an individual of the *Lufengpithecus* genus—was discovered. At about 6.1 million years old, the fossil's age corresponds to the strongest of the three cooling episodes, which, according to the authors, is in line with the idea that these episodes and their effects on vegetation could have promoted the local disappearance of great apes.

The authors note that the precise timing of great apes' disappearance in the Yunnan region is unknown and that further research is needed to confirm whether they indeed went extinct or they evolved into a different lineage in other regions. (*Geophysical Research Letters*, https://doi.org/10.1029/2020GL087741, 2020) **—Sarah Stanley,** *Science Writer*

This skull fragment of a specimen of the great ape Lufengpithecus *cf.* lufengensis *was unearthed in the Yunnan region of China and dates to the late Miocene. Credit: Xueping Ji*

Top: Unsplash/Tom Ezzatkhah

How Will Climate Change Affect Arctic Stream Slime?

Biofilms are hubs of microbial activity in streams. These complex matrices of algae, fungi, and bacteria—sometimes called microbial skin for their critical role in processing nutrients—adhere to streambeds in slippery mats. Despite their importance in biogeochemical processing in streams globally, researchers know very little about how stream biofilms in some parts of the world, such as the Arctic, respond to shifts in nutrient availability, a critical knowledge gap as climate change rapidly reshapes that part of the globe.

Indeed, the Arctic region is warming significantly faster than the global average. As permafrost thaws, microbes in the formerly frozen soil become more active, breaking down organic matter and releasing more nutrients into the environment, which can be carried away in seasonal meltwater. Here *Pastor et al.* study how changes in nutrient (e.g., nitrogen and phosphorus) availability in streams fed by thawing permafrost and seasonal snowmelt influence biofilm growth.

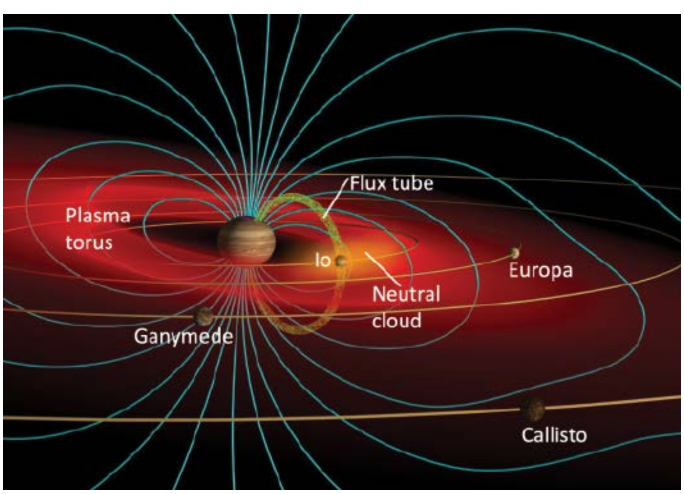
The team looked at two streams in Greenland's Zackenberg Valley, a region of the High Arctic where summertime temperatures typically top out at about 4.5°C (40°F), and chose six sampling locations representing a broad range of hydrological conditions and nutrient concentrations. To measure biomass accrual, the researchers used glass disks, either untreated or preloaded with nutrients, as substrates to mimic surfaces in streams where biofilms would accumulate. They placed these artificial substrates into the streams in the late summer, at the peak of seasonal thaws. Although many previous studies on stream biofilms measured biofilm growth by tracking only algal chlorophyll, the methods here also account for fungal and bacterial communities in biofilms. The team also monitored other stream conditions such as water temperature, flow velocity, and nutrient concentrations.

Overall, the researchers found that nitrogen concentrations, which are typically low in High Arctic streams, had a strong influence on biofilm growth. Biomass levels were highest at upstream sampling sites, where nitrate levels were up to 10 times higher than at downstream locations. The results suggest that climate change impacts in the Arctic, including the downslope flow of nutrients from soils, are likely to affect biofilm growth in the region's streams. (*Journal of Geophysical Research: Biogeosciences*, https://doi.org/10.1029/2019JG005557, 2020) **—Kate Wheeling,** *Science Writer*

Two Moons and a Magnetosphere

Jupiter's two innermost moons, Io and Europa, play a central role in sculpting and interacting with the planet's magnetosphere, the vast region where Jupiter's magnetic field influences a swirling mass of charged particles surrounding the planet and its many moons.

In a new review, *Bagenal and Dols* pull together decades of research on this intricate system. Whereas prior reviews have focused on either Io's or Europa's space environment alone, this paper addresses both in harmony. It draws on data from the early Voyager missions, later flybys by other spacecraft, the latest Earth-based observations, innovative computational modeling efforts, and more.



Jupiter's moons Io and Europa interact significantly with the planet's massive magnetosphere. Every second, for example, roughly a ton of neutral atoms from Io's atmosphere are ionized and become part of the plasma torus that encircles the planet. Credit: John Spencer, Southwest Research Institute

The researchers paint a detailed picture of what is known about the two moons' individual atmospheres. While Io's is thought to consist mostly of sulfur dioxide, Europa's is mostly oxygen. Each moon's atmosphere interacts with the magnetosphere's charged particles, known as plasma, causing clouds of neutral atoms to escape from the atmospheres.

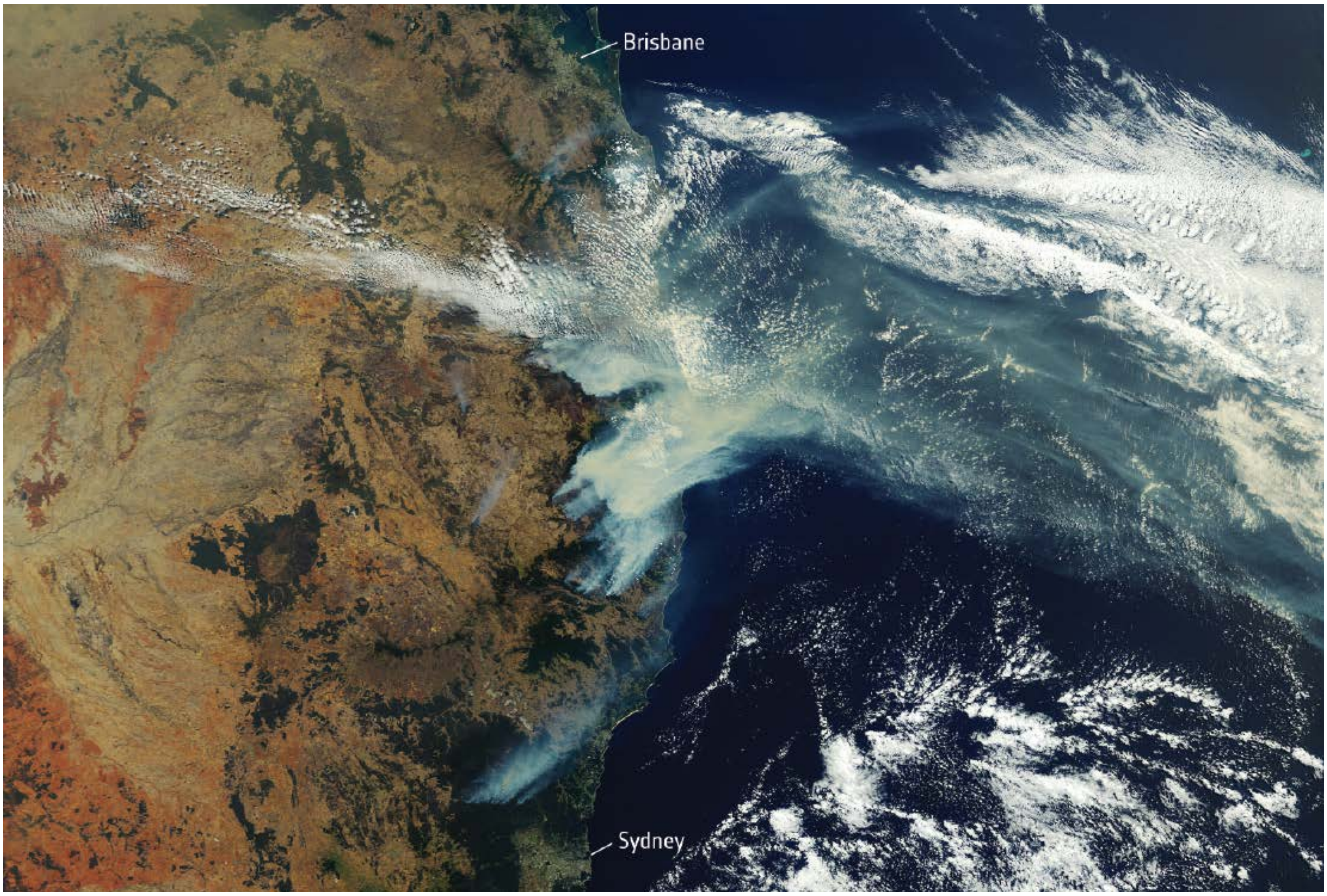
In turn, these neutral clouds serve as the primary source of new plasma in Jupiter's magnetosphere: Existing plasma electrons ionize neutral atoms, transforming them into charged plasma particles.

Io plays a particularly intriguing role in this system. At any given moment, 50–100 of its many volcanoes are actively erupting, emitting sulfur dioxide into the moon's atmosphere. Every second, roughly a ton of this gas becomes plasma that feeds an ever present doughnut-shaped belt, or torus, of dense plasma that encircles Jupiter.

Although many details of these physical processes have become clear in recent years, questions remain. For instance, what are the precise compositions of the moons' atmospheres? How do plasma-atmosphere interactions vary at different locations around each moon? And what impact do changes in Io's volcanic activity have on the system?

The ongoing Juno mission, Earth-based observations, and computational modeling should continue to provide new insights into the Io-Europa-magnetosphere system. In the future, NASA's Europa Clipper and the European Space Agency's Jupiter Icy Moons Explorer (JUICE) missions promise to illuminate more about Europa, which is thought to harbor an intriguing liquid ocean under its icy crust. The authors note that a flyby mission to Io is needed to answer many questions about its unique role. (*Journal of Geophysical Research: Space Physics*, https://doi.org/10.1029/2019JA027485, 2020) **—Sarah Stanley,** *Science Writer*

A Revised View of Australia's Future Climate



Smoke from fires along Australia's eastern coast billows out over the Tasman Sea in November 2019. Credit: Contains modified Copernicus Sentinel data (2019), processed by the European Space Agency, CC BY-SA 3.0 IGO (bit.ly/ccbysaigo3-0)

On the heels of an unprecedented wildfire season, climate is yet again a hot topic in Australia. In a new study, researchers examine the performance and projections of the latest generation of global climate models for the Australian continent.

Efforts to understand how climate change will unfold under various emissions scenarios rely on the sophisticated computer models of the Coupled Model Intercomparison Project (CMIP), which combines dozens of models to create as complete a picture of Earth's climate as possible. The recently released sixth phase of CMIP incorporates several new features, including a more diverse set of emissions scenarios that correspond to possible future socioeconomic changes in the world. It also allows researchers to compare results from the new models with those from previous CMIP generations, addressing whether the models simulate the current climate any better and whether they give new insights about the future.

In the new study, *Grose et al.* conclude that the CMIP6 models do improve on CMIP5 in incremental but important ways. The models more accurately capture the impact of large-scale climate drivers on rainfall, represent dynamic sea level, and simulate extreme heat events in the atmosphere and in the surrounding ocean.

The researchers write that the projections of future conditions broadly agree with the data from CMIP5, thereby increasing confidence in most aspects of the existing projections. However, although both generations of models project further warming in the coming century, the upper range of the CMIP6 predictions beyond 2050 is higher than in CMIP5 models, meaning a worst-case scenario could be even worse than previously thought. The scientists say that these higher values in some CMIP6 models arise largely because the models have higher "climate sensitivity" to greenhouse gas increases. If these models are, in fact, the most credible, then limiting global warming to less than 2°C—the goal established in the Paris Agreement—will require larger emissions reductions than previously thought. (*Earth's Future*, https://doi.org/10.1029/2019EF001469, 2020) —**David Shultz**, *Science Writer*

How Does a Greening Arctic Affect Groundwater Recharge?

Researchers are studying thawing permafrost in the Canadian tundra, seen here, to find out how shifts in surface ecology might affect hydrology. Credit: ADialla, CC BY 2.0 (bit.ly/ccby2-0)

Rising temperatures around the globe are rapidly thawing permafrost, and a fifth of frozen soil underlying tundra around the world could thaw by 2040, even if we take drastic steps to mitigate climate change. As permafrost thaws, landscapes change.

In the Tasiapik Valley of northern Quebec, Canada, which lies within the discontinuous permafrost zone, vegetation cover has been increasing since the 1950s. Where open tundra, lichen, and herbs once dominated, shrubs and black spruce forests have expanded as the average temperature has climbed. Previous research showed that the land cover in the region evolves over an estimated 90-year-long period from an immature landscape of lichens and herbs underlain by permafrost to a mature one of trees and shrubs, without permafrost. In a new study, *Young et al.* sought to determine how this progression affects groundwater recharge in the region's catchments.

They used the water table fluctuation method to evaluate groundwater recharge at study sites in the valley that included five types of land cover: tundra (or permafrost), lichens and herbs, low shrubs and lichens, medium shrubs, and trees. During field campaigns in 2012 and 2014, the team installed piezometers and water and temperature probes to estimate groundwater recharge rates at each site over the course of four hydrological years (in North America, the hydrological year runs from 1 October to 30 September).

The team found that as vegetation height increases, the depth of freezing decreases and the date of the first belowground freeze occurs later. All the sites thawed around the same time, however, when temperatures climbed above freezing. Across all sites and in each hydrological year, the authors saw a shift in the timing of the first water level rise that coincided with the first spring melt. In areas with the tallest vegetation, the water level rise occurred up to a month later than in regions with the shortest vegetation. The delay, the authors note, likely results from trees and taller shrubs shading the local snowpack and slowing down melt. As a result, instead of quickly flowing toward rivers and streams, meltwater can slowly soak into the soil, which allows for more groundwater recharge.

Ultimately, the impact of greater groundwater recharge in forested areas also depends on other factors, such as the depth of the snowpack and the location of underground aquifers. Future studies incorporating models of unsaturated zone dynamics could further refine our understanding of the effect that climate change will have on Arctic groundwater recharge. (*Geophysical Research Letters,* https://doi.org/10.1029/2020GL087695, 2020) **—Kate Wheeling,** *Science Writer*

Atmospheric Sciences

The Faculty of Mathematics and Natural Sciences at the University of Rostock is involved in a joint appointment procedure with the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V.) (DLR) and invites applications for a University Professorship (W3) for Solar Terrestrial Physics to commence work at the earliest possible date. The successful applicant will be assigned to the University of Rostock as a university professor with a reduced teaching obligation (2 SWS) and in parallel will undertake the position of the Director of the DLR Institute for Solar-Terrestrial Physics in Neustrelitz.

Women with essentially equivalent qualifications will be given priority provided that the personal qualities of a male candidate are not better suited for the position.

Further information about the position, and application process can be found under https://www.uni-rostock.de/en/stellen/professuren/

Biogeosciences

Assistant Professor (tenure track) in Geo-Environmental Data Science

Introduction

The University of Lausanne is a higher teaching and research institution composed of seven faculties where approximately 15,000 students and nearly 5,000 employees, professors, and researchers work and study. Ideally situated along the Lake of Geneva, near Lausanne's city center, its campus brings together over 120 nationalities.

Presentation

The Faculty of Geosciences and the Environment (FGSE) of the University of Lausanne invites applications for a professorship in geo-environmental data science, to be based in the Institute of Earth Surface Dynamics (IDYST).

We are looking for a scientist at the intersection of data science and geo-environmental science who complements current strengths of the FGSE. As far as data science, we seek someone able to develop methods/algorithms (such as machine learning, geostatistics, geocomputing, geomodelling, etc.) and tailor them to particular large spatial/temporal datasets or big data. As far as geo-environmental science, the person is expected to analyse and predict the dynamics of the earth surface-environmental system (such as hydrology, geomorphology, vegetation distribution, climate, environmental data time series, soils, etc.). The appointed person will teach GIS along with other geo-environmental data science courses.

Information

Appointment will be at the Assistant Professor level (tenure track). However, exceptionally, we will consider outstanding candidates for direct appointment to the Associate Professor level, notably if this corresponds with our equal opportunity objectives.

Starting date: August 1st, 2021 (or to be agreed upon)

Contract length: 2 years renewable twice (6 years). Tenure and promotion to the rank of Associate Professor expected after 5-6 years, leading to further contracts renewable every 6 years.

Activity rate: 100 %

Workplace: Lausanne campus (Géopolis building)

Your Responsibilities

The successful candidate is expected to i) develop a competitive research program within the Institute of Earth Surface Dynamics, ii) teach courses in the Bachelor of Geosciences and Environment, and Masters programs taught by the FGSE, and, iii) supervise masters and doctoral students.

Your Qualifications

Candidates must demonstrate a capacity to undertake quality research, to obtain competitive research funding, and to publish in peer-reviewed international research journals. A demonstrated potential for teaching GIS, best practice programming skills, data science applied to geo-environmental problems, or algorithms is highly desirable. In addition, the candidate has demonstrated potential for supervising master's and doctoral theses.

A good command of both French and English language is preferable. If French is not the native language, teaching ability in French has to be acquired within two years of the appointment.

What the position offers you

The Faculty of Geosciences and the Environment (FGSE) of the University of Lausanne was created in 2003 and offers state-of-the-art field and laboratory equipment (e.g., XRD, RockEval, Carlo Erba, SEM, mercury and phosphorus analysis, stable isotopes, compound specific-light isotopes, clumped isotopes, XRF, SIMS and NanoSIMS, Luminescence dating, LA-ICPMS, ICP-OES, Electron Microprobe, X-Ray tomography, GPU and CPU-based supercomputing facilities, remote sensing equipment including a drone lab, as well as instrumented field sites), incentives for projects, and "excellent working conditions" (https://www.unil.ch/srh/home/menuinst/infos-administratives/donnees-salariales.html). It consists of three

research institutes (Earth Sciences, Geography and Sustainability, and Earth Surface Dynamics) and a School that manages teaching and training across these research domains. The FGSE specifically promotes interdisciplinary research and teaching, within and between the social and natural sciences.

Contact for further information

Other useful information is available on the websites of the Faculty (www.unil.ch/gse) and the Institute of Earth Surface Dynamics (www.unil.ch/idyst)

For further information, contact the Chair of the selection committee for this position: Christian Kull, Vice-Dean of the FGSE, and Professor in the Institute of Geography and Sustainability (christian.kull@unil.ch).

Application deadline: September 1st, 2020 (23:59 Swiss time GMT+2)

The PDF application must be shared in several documents not larger than 9.9 MB and can only be submitted through this website:

https://bit.ly/2BBqAfm

Or www.unil.ch/central/en/home.html -> Careers at UNIL -> Emplois -> Postes ouverts -> English -> Keywords Data science (or ad 16162) and should include:

- a cover letter, addressed to the Dean, explaining the reasons for applying (max. 1 page);
- a full Curriculum Vitae, including previous employment and university training, the date and title of the doctoral thesis, publications, conference presentations / invited lectures, classes taught, and student research supervised;
- a research statement, describing the research the candidate intends to develop (max. 4 pages);
- a teaching statement, describing the candidate's teaching approach, intentions for teaching and his or her potential contribution to our teaching programs (max. 2 pages);
- PDFs of the five most relevant publications;
- the names and contact information of five referees.

Additional information

The University of Lausanne seeks to promote an equitable representation of men and women among its staff and strongly encourages applications from women. The FGSE's strategy regarding equal opportunity, specifically with respect to the recruitment of professors, is described in point 2.2 of the FGSE's Plan of action in favor of the equality of chances between women and men 2017-2020.

Candidates are expressly invited to consult this document at the following website: https://www.unil.ch/gse/fr/home/menuinst/faculte/commissions/egalite.html

The Faculty of Geosciences and Environment of the University of Lausanne adheres to the DORA: https://sfdora.org/ agreement and follows its guidelines in the evaluation of applications.

Geodesy

Job Summary

The Geology & Geophysics Department at Woods Hole Oceanographic Institution (WHOI) invites exceptional candidates to apply to one or more of our full-time exempt tenure track positions on our scientific staff. We seek to hire at the Assistant Scientist level; however, extraordinary candidates may be considered at Associate Scientist without Tenure, Associate Scientist with Tenure, or Senior Scientist levels.

The successful candidate would ideally have expertise in Seismology or Geodesy (marine or terrestrial), and an interest in the use and/or development of marine instrumentation and novel techniques for analyzing seafloor data. WHOI currently houses the Ocean Bottom Seismometer Instrument Center (OBSIC) (https://obsic.whoi.edu/) which provides seafloor instrumentation for the US seismic community. Individuals who are able to develop synergies and collaborations with OBSIC would be desirable.

However, candidates from other geophysical fields, whose expertise complements and strengthens that of the department may also be considered and are encouraged to apply. Existing departmental strengths and interests include geophysics (active and passive seismology, electromagnetic methods, and magnetics), tectonics, ice-sheet dynamics, volcanology and fluid dynamics, geochemistry, coastal processes, past and present climate dynamics and biogeochemistry.

WHOI is the largest private, nonprofit oceanographic institution in the world, with staff, postdocs, and graduate students numbering approximately 1,000. Its mission is to advance our understanding of the ocean and its interaction with the Earth system, and to communicate this understanding for the benefit of society. The Institution is located in Woods Hole, Massachusetts, a world-renowned center of excellence in marine, biomedical, and environmental science. An additional 500 affiliates are associated with the scientific endeavors of the Institution, many of whom are foreign nationals from the international community.

WHOI is committed to supporting a diverse and inclusive environment and is proud to be an equal opportunity employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, gender, gender identity or expression, sexual orientation, national origin, genetics, disability, age, or veteran status. WHOI believes diversity, equity, and inclusion are essential components that support our academic excellence. We strive for a diverse and inclusive workforce, and encourage women, minorities, veterans and those with disabilities to apply.

WHOI offers a comprehensive benefit package that includes medical and dental plans, short-term and long-term disability and life insurance programs, medical and dependent care pre-tax Flexible Spending Accounts in addition to our own child care subsidy reimbursement program, paid parental leave, a generous employer contribution retirement plan, vacation, occasional illness, and family illness time as well as flexible work arrangements. WHOI also provides dual career services for assisting your spouse or partner should they be impacted by your career decision. We have a dedicated team who will work with applicants to identify and explore available options within WHOI or the broader community.

Essential Functions

Opportunities for interdisciplinary research exist and are highly encouraged, through collaborations with colleagues in our other science departments, centers, and labs as well as with researchers in the broader Woods Hole scientific community. WHOI's Scientific Staff members are expected to provide for their salaries and those staff members who work in support of their research from grants and contracts that they have been awarded. The Institution provides salary support when no other funding is available. There are also opportunities for significant internal funding to develop innovative research projects. Candidates hired at the junior non-tenure level will receive an initial appointment for four years.

Education & Experience

Applicants should have a doctoral degree, postdoctoral experience, and a record of scientific research publications in scholarly journals. Scientific staff members are expected to develop independent, externally-funded, and internationally-recognized research programs. They also have the option of advising graduate students and teaching courses through the MIT/WHOI Joint Program in Oceanography and Oceanographic Engineering.

Special Requirements

Applicants should upload, in the designated areas of the application, the following documents. Please include the title of the position that you are applying for in the name of your files: A cover letter; curriculum vitae (CV); three-page research statement; names of four references; and copies of up to three relevant publications. In addition to the online application, please email the documents directly to the chair of the Geology & Geophysics Department at gg-chair@whoi.edu with the subject 'Geology & Geophysics Scientist Application'. Interviews will be conducted virtually.

Physical Requirements

Further details of the physical requirements of established essential functions for this position will be addressed/discussed during the interview process.

Hello from the southern tip of South America!

The SouthTRAC campaign is an atmospheric research project led by German research centers and universities to measure meteorological quantities and trace gases in the lower and middle atmosphere over South America. Its star is the German High Altitude and Long Range Research Aircraft, or HALO, in the photo here. (I'm pointing to the nose cone, which holds the Basic Halo Measurement and Sensor System, or BAHAMAS, which takes measurements of velocity, pressure, temperature, humidity, and aircraft position.)

In September and November 2019, HALO flew over Río Grande in the Tierra del Fuego province of Argentina, at the southern tip of the continent. In this cold region, we experienced wind surges of almost 90 kilometers per hour during the final days of the campaign.

Our scientific objectives were to study the coupling processes at the tropopause; the generation, propagation, and dissipation of gravity waves; the impact of the Antarctic vortex on the upper troposphere and lower stratosphere; and biogenic emissions in the upper troposphere. Previous studies have shown that this region over South America is unique regarding the intensity of gravity waves. HALO is equipped with 13 instruments that allow us to study the atmospheric composition and dynamical parameters by in situ sampling and remote sensing.

We complemented HALO's observations with those from ground-based instruments and a glider operating at El Calafate, Argentina. Groups in Europe, Argentina, Chile, and the United States collaborated in these activities. Read more about our work at https://bit.ly/southtrac.

—**Peter Alexander,** Grupo de Dinámica Atmosférica, National Scientific and Technical Research Council (CONICET), Buenos Aires, Argentina

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